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CONTENTS.

PART I. (1894–96.)

NUMBER — PAGE

I. *The Clyde Sea Area.* By Hugh Robert Mill, D.Sc., F.R.S.E. Part III.—Distribution of Temperature. (With Thirty-two Plates), 1

II. *A Fundamental Theorem regarding the Equivalence of Systems of Ordinary Linear Differential Equations, and its Application to the Determination of the Order and the Systematic Solution of a Determinate System of such Equations.* By George Chrystal, M.A., LL.D., Professor of Mathematics in the University of Edinburgh, . 163

III. *On Bird and Beast in Ancient Symbolism.* By Professor D'Arcy Wentworth Thompson, Jr., ... 179

IV. *Two Glens and the Agency of Glaciation.* By His Grace The Duke of Argyll, K.G., K.T. (With a Map), ... 193

V. *On the Fossil Flora of the Yorkshire Coal Field.* (First Paper.) By Robert Kidston, F.R.S.E., F.G.S. (With Three Plates), . . 203

VI. *Experiments on the Transverse Effect and on some Related Actions in Bismuth.* By J. C. Beattie. (With a Plate), ... 225

VII. *On the Relation between the Variation of Resistance in Bismuth in a Steady Magnetic Field and the Rotatory or Transverse Effect.* By J. C. Beattie. (With a Plate), ... 241

PART II. (1895–96.)

NUMBER PAGE

VIII. *On the Comparative Histology and Physiology of the Spleen.* By A. J. WHITING, M.D. (With Three Plates), ... 253

IX. *Specific Gravities and Oceanic Circulation.* By ALEX. BUCHAN, M.A., LL.D. (With Nine Maps) 317

X. *On the Deep and Shallow-water Marine Fauna of the Kerguelen Region of the Great Southern Ocean.* By JOHN MURRAY, D.Sc., LL.D., Ph.D., of the Challenger Expedition. (With a Map), . . . 343

XI. *On a Case of Colour Blindness.* By WM. PEDDIE, D.Sc. Part I. (With a Plate), ... 501

PART III. (1896.)

XII. *The Development of the Müllerian Duct of Amphibians.* By GREGG WILSON, M.A., B.Sc., Edin. (With Two Plates.) *Communicated by* Prof. COSSAR EWART, M.D., F.R.S., ... 509

XIII. *The Strains Produced in Iron, Steel, and Nickel Tubes in the Magnetic Field.* Part I. By Professor C. G. KNOTT, D.Sc., F.R.S.E. (With Six Plates), ... 527

XIV. *A Revised Description of the Dorsal Interosseous Muscles of the Human Hand, with Suggestions for a New Nomenclature of the Palmar Interosseous Muscles, and some Observations on the Corresponding Muscles in the Anthropoid Apes.* By DAVID HEPBURN, M.D., C.M., F.R.S.E., Lecturer on Regional Anatomy in the University of Edinburgh. (With a Plate), ... 557

XV. *The Temperature Variation of the Magnetic Permeability of Magnetite.* By EDWIN H. BARTON, D.Sc. (Lond.), F.R.S.E., A.I.E.E., Senior Lecturer and Demonstrator in Physics at University College, Nottingham. (With Three Plates), ... 567

NUMBER PAGE

XVI. *The Weather, Influenza, and Disease: from the Records of the Edinburgh Royal Infirmary for Fifty Years.* By A. Lockhart Gillespie, M.D., F.R.C.P.E.; Memb. Scot. Met. Soc.; Medical Registrar, Edinburgh Royal Infirmary. (With Six Plates), . 579

XVII. *The s' of Diophantus.* By Prof. D'Arcy Wentworth Thompson, . 607

XVIII. *On Torsional Oscillations of Wires.* By Dr W. Peddie. (With Two Plates), ... 611

XIX. *On the Cranial Nerves of* Chimæra Monstrosa (Linn. 1754): *with a Discussion of the Lateral Line System, and of the Morphology of the* Chorda tympani. By Frank J. Cole, Demonstrator and Assistant Lecturer of Zoology, University College, Liverpool. *Communicated by* Professor Ewart, M.D., F.R.S. (With Two Plates), . . 631

XX. *The Meteorology of Edinburgh.* By Robert Cockburn Mossman, F.R.S.E., F.R.Met.Soc. (With Three Plates), . . . 681

XXI. *On the Curves of Magnetisation for Films of Iron, Cobalt, and Nickel.* By Dr J. C. Beattie. (With a Plate), ... 757

PART IV. (1896.)

XXII. *Observations on the Phonograph.* By John G. M'Kendrick, M.D., Professor of Physiology in the University of Glasgow. (With Two Plates), ... 765

XXIII. *On the Genus* Anaspides *and its Affinities with certain Fossil Crustacea.* By W. T. Calman, B.Sc., University College, Dundee. *Communicated* by Professor D'Arcy W. Thompson. (With Two Plates), . 787

XXIV. *On the* p-*discriminant of a Differential Equation of the First Order, and on Certain Points in the General Theory of Envelopes connected therewith.* By Professor Chrystal, ... 803

PAGE

APPENDIX—

The Council of Society, ... 829

Alphabetical List of the Ordinary Fellows, ... 831

List of Honorary Fellows at March 1897, ... 847

List of Ordinary Fellows Elected during Session 1894–95, . . 849

Fellows Deceased or Resigned, 1894–95, ... 850

List of Ordinary Fellows Elected during Session 1895–96, . . 851

Fellows Deceased or Resigned, 1895–96, ... 852

Laws of the Society, ... 853

The Keith, Makdougall-Brisbane, Neill, and Gunning Victoria Jubilee Prizes, ... 860

Awards of the Keith, Makdougall-Brisbane, Neill, and Gunning Victoria Jubilee Prizes, from 1827 *to* 1896, ... 863

Proceedings of the Statutory General Meetings, 1894 *and* 1895, . . 869

List of Public Institutions and Individuals entitled to receive Copies of the Transactions and Proceedings of the Royal Society, . . 875

Index, ... 882

TRANSACTIONS.

I.—*The Clyde Sea Area.* By Hugh Robert Mill, D.Sc., F.R.S.E. (Plates I.–XXXII.)

Part III.—Distribution of Temperature.

(Read June 19, 1893.)

Preliminary.

The first two parts of this paper—*Physical Geography* and *Salinity*—were communicated to the Society on May 18th, 1891, and published in the *Transactions*, Vol. XXXVI., Part III., No. 23, pp. 641–729.

Various circumstances have prevented me from sooner presenting the concluding part of the discussion. I postponed publication again and again, in the hope that it might be possible to discuss the results more thoroughly, and deduce from them more clearly than I have been able to do the laws which regulate the heat-transactions of sea-water of varying salinity, contained in basins of differing degrees of isolation from the circulation of the ocean. At length the conclusion has been arrived at that the observations are not sufficiently uniform, regular, and close to warrant the expenditure of the time devoted to their discussion. Many months of work have been occupied in proving that some special manner of classifying and treating the data led to no definite result. Thus, it is unnecessary to describe several series of voluminous calculations, or to bring forward a great number of maps and sections on which the distribution of temperature was plotted in different ways. It is difficult to establish theoretical conclusions of a general and far-reaching kind from my work, and I have not attempted to compare it with the many memoirs published in continental journals, on the temperature of lakes, fjords, and enclosed seas. During the last few years it has only been possible for me to discuss the results in spare hours, snatched from the engrossing occupations of University Extension lecturing, and literary work in other departments of science, so that I have never been able to master simultaneously the crowd of details, but obliged to treat each unit of the work separately, returning to it often after weeks in which the earlier discussions had been partly forgotten. Thus the

memoir is, in large measure, a patchwork or agglomeration of minor discussions, the result of the attempt to do a piece of original work in physical geography in a country where there is scant recognition in the Universities of such special study or research. I must, however, record my indebtedness to the temporary Elective Fellowship in Experimental Physics in the University of Edinburgh, which enabled me to devote two years exclusively to the practical work of carrying out observations, and to the Government Grant Committee for sums of money which sufficed to pay for such additional assistance as was required in carrying out the discussion. Without such help, the work would have been impossible. Any value it now possesses lies in the fact that it is a presentation of actual observations made at the same stations, with the utmost care, and by precisely the same methods, although at somewhat irregular intervals of time, for three and a half years. These observations were published partly in the *Journal* of the Scottish Meteorological Society * and partly in the *Proceedings* of this Society.† Here they are arranged in the manner which, after repeated trials, seems to be that best adapted to bring out their characteristic features: in some aspects they are generalised, and in every case, as far as possible, brought into connection with the related tidal or climatic phenomena.

One of the most instructive results is that the omission of one or two sets of observations would give an entirely different complexion to the whole series. Not only might the date of a seasonal maximum or minimum be missed in this way, but the sudden and profound disturbances of seasonal changes, which are otherwise apparently uniform, would pass undetected. These irregular changes make it doubtful whether any one year can be fairly compared with any other. The determining conditions of temperature-change are much more numerous and complicated than was suspected from the preliminary discussions made while the observations were in progress.‡ Thus it now appears that it is necessary to know the direction and force of the wind, not only at the time when the observations were made, but every day during the whole period of observation. And since the direction of the wind is modified by the configuration of the land around each loch, it is impossible to arrive at the actual directions from a study of the weather-charts. There are practically no meteorological stations in the landward division of the Area, so that no contemporary observations of wind are available. These limitations have been carefully kept in view, and I have endeavoured to carry each train of reasoning no farther than is justified by the ascertained facts.

It was originally my ambition to calculate out the total changes of heat for the whole Clyde Sea Area looked upon as a closed system; but after working long at the problem I was obliged to abandon it on account of the small number of observations in the seaward part, and the unknown influence of the wide margin of shallow water along the Ayrshire coast. A fairly good guess may be made of the total amount of heat at the time

* *Journ. Scot. Met. Soc.*, 3rd ser. (1886), vol. vii., No. 3, pp. 313–351 (1887), vol. viii., No. 4, pp. 47–110.

† *Proc. Roy. Soc. Edin.*, vol. xviii., pp. 139–228.

‡ Physical Conditions of the Water in the Clyde Sea Area, *Proc. Glasgow Phil. Soc.*, vol. xv*iii.* (1887), pp. 332–356.

of the annual minimum, when the temperature appears to become uniform both in regional and bathymetrical distribution. At other times, however, it was only found possible to estimate the heat-content of the water in small and well-defined natural regions.

In presenting this paper, I have to express my thanks to many friends and fellow-workers for advice and assistance. Dr JOHN MURRAY, who initiated and directed the whole work, has, at various stages, given the most helpful suggestions, and the observations made in the later trips of the "Medusa" were done entirely under his supervision or by himself personally. Mr J. Y. BUCHANAN, F.R.S., kindly gave the use of his observations on Loch Lomond, for comparison with those on the lochs of the Clyde Sea Area. Mr A. J. HERBERTSON and Mr R. TURNBULL drew all the curves of vertical distribution of temperature for each station; Dr W. PEDDIE estimated the mean temperature of each of the curves; while Mr H. N. DICKSON estimated the mean temperature of the various loch-basins from the vertical sections, and rendered other help.

Instruments and Methods.

Surface Temperature.—The temperature of the surface water was observed in two different ways, which gave practically identical results. When a serial temperature-sounding was made, the Negretti and Zambra reversing thermometer was employed, the frame of the instrument being just immersed, so that the bulb was about six inches below the surface. On other occasions, when it was desirable to obtain the surface temperature without stopping the vessel, a bucketful of surface water was taken on board, and a mercurial thermometer, with large bulb and stem divided into degrees Fahrenheit, immersed in it. The bucket was placed in the shade, and the thermometer left in it for about two minutes, being used to stir the water thoroughly before it was read. Care was always taken to draw the sample of water well forward in the vessel, so that there could be no possibility of admixture of warm water from the condenser or any discharge-pipe. The error of the surface thermometer was carefully ascertained, at intervals of a few months, by comparison with a standard thermometer.

Deep-Sea Thermometer.—For observations beneath the surface the instrument exclusively employed was NEGRETTI and ZAMBRA'S Patent Standard Deep-Sea Thermometer. All thermometers used were graduated on the Fahrenheit scale, which presents many advantages for observational purposes, and all temperatures are given on that scale. The principle of the thermometer is well known. It is in fact an out-flow thermometer, in which the mercury that escapes from the bulb is measured instead of being weighed. There is a constriction in the stem just above the bulb, and then the bore is enlarged into a small lateral pouch or chamber. In an upright position the thermometer acts like any other, but when it is inverted the mercury column breaks off at the constriction and runs into the tube, which is graduated in degrees so as to be read in the inverted position. The whole thermometer is sealed up in a strong glass tube to protect it against pressure, and the bulb is surrounded with mercury to transmit the heat rapidly.

After the thermometer is inverted, the record of the temperature remains unchanged,

except for the slight expansion or contraction of the broken-off column by change of temperature. I made a series of experiments on the temperature correction of eight of these thermometers, and found, as the average of many trials, that a change of 60° F. lengthened the broken-off column by 1° of the scale, the temperatures employed being 32° and 92°. Hence for a change of 6° between the temperature of reversing and that of reading, a correction of one-tenth should apparently be applied. In summer, for instance, a thermometer reversed at 45°, hauled up rapidly, and read in air at 65°, might appear to require a correction of 0°·3; but, recollecting that the thermometer is read before it has time to assume the temperature of the air, and that it is wet, we see that the amount of correction should be considerably less. If the thermometer is hung up in the wind for five minutes, and kept wet all the time (for it would be impossible to dry it thoroughly), the wet bulb temperature of the air, ascertained by a sling thermometer, might be used to correct the readings. Or, more simply, the inverted thermometer may be placed for a few minutes, before reading it, in a bucket of surface water, the temperature of which can easily be noted, and the corresponding correction applied. This was done on several occasions when the difference of temperature between water and air was over 10°,—a state of matters which rarely occurred in the Clyde Sea Area, except for the bottom temperatures of Loch Fyne and Loch Goil in summer. A simpler method, subsequently adopted, was to read the thermometer as it came up, then right it sharply, and immediately reverse again, the second reading giving the exact temperature of the instrument at which the first reading was made. In preparing the results for publication it was not found necessary to apply this special correction.

The thermometers acquired a considerable index error in the time during which they were used: in one case it amounted to as much as 0°·5. This error was determined periodically by the use of melting ice, and of water at a higher temperature in which a standard thermometer was immersed. In calm weather, and by the use of ordinary precautions to insure correct readings, the observations could be trusted to 0°·1 F. Although well suited for work in a climate like that of the West of Scotland, in most of the thermometers I have examined the pouch-shaped recess is not large enough to contain the overflow from the bulb when the temperature is raised 60° or more after inversion; and in other cases, although the pouch is large enough to hold the overflow, a very slight jerk is sufficient to carry it past the siphon bend, and so vitiate the record. The bulb of the thermometer being filled with mercury and surrounded by it, very rapidly accommodates itself to the temperature of the water in which it is immersed. From experiments made at different times it appears that in ordinary circumstances less than a minute suffices; but when the difference of temperature exceeds 5° two minutes may be necessary. In order to make perfectly sure of equilibrium of temperature being arrived at between bulb and water, it was usual to leave the thermometer at the depth where it was wanted to register for at least three minutes before causing it to reverse. In the case of the first sounding at any station when the thermometers had remained for some time exposed to atmospheric temperature, an immersion of five minutes was the minimum.

The glass-encased thermometer is fixed by means of thick indiarubber rings and washers in a perforated brass case, and some observers have found that these rings tended to make the instrument somewhat sluggish in its action. I only observed this effect on two occasions when the rings had got displaced, and, blocking the perforations, checked the flow of water between the brass tube and the bulb. On altering the position of the rings there was no further trouble.

There is no question as to the perfect suitability of the Negretti and Zambra thermometer for all marine work where the exact temperature at a given position is required. There is, however, considerable difference of opinion as to the best mechanism for insuring inversion of the thermometer at the wished-for point. I have never used the original wooden float with shot counterpoise, nor do I think that satisfactory results ever attended its employment. MAGNAGHI'S frame was a marked improvement. In it the thermometer mounted on trunnions is held upright in the frame by a pin, which is raised by the action of the rush of water past a screw propeller, on the instrument being drawn up. At first there were two blades on the propeller, but the addition of a third gave it much greater certainty in working. When the thermometer falls over, it is clamped by a side spring, and retained in its inverted position until reset. A light indiarubber band passed round the upper part of the frame insures that the reversal takes place immediately on the pin being withdrawn. The Magnaghi frame in its original form, and with the addition of many modifications, has been largely used for deep-sea work, and has given considerable satisfaction. The work of the Scottish Marine Station in shallow water and amongst rapid currents soon revealed a number of defects. When the screw was arranged so as to reverse the thermometer when hauled up through less than one fathom, it was often set off by the pitching of the ship or by the force of the current; and when adjusted for a longer haul, the exact depth at which the instrument turned over could not be ascertained, and it was impossible to get bottom temperatures. The method of attachment to the sounding-line by lashings was also found to be troublesome and slow, especially in cold and wet weather. The Scottish frame was accordingly devised. It is a modification of MAGNAGHI'S, the screw pin with its revolving gear being replaced by a simple pin actuated by a lever, which is depressed by a weight or "messenger" slipped down the line, striking on the forked outer branch. A vice-clamp serves to fix the frame to the sounding-line at any point, and with great rapidity. The final form of frame was not arrived at until after many experiments, but thousands of observations have shown it to be convenient and trustworthy. The form which was found most convenient is figured in Plate I., and a sufficient description is attached to show the object of the various parts. An improved form of clamp to secure the instrument when reversed has been introduced by Messrs NEGRETTI and ZAMBRA, and is smoother in action than that shown in the figure.

RUNG'S extremely ingenious messengers, made in two pieces, which can be fitted together on any part of the line, are used for the Scottish frame.

The importance of having thermometers which can be made to register at any given depth is very great. For instance, the temperature of the surface at Clapochlar, Loch

Strivan, was 42°·0 on one occasion in February 1887, at 5 fathoms 42°·1, at 10 fathoms 44°·4, at 15 fathoms 45°·0, and at the bottom (35 fathoms) 44°·1. Closer observations showed that at 8 and 9 fathoms the temperature was 42°·1, while at 9½ fathoms it was 44°·4, showing a rise of 2°·3 in 3 feet, and a change of only 0°·1 in the 54 feet above. In shallow estuaries almost all the change of temperature between surface and bottom sometimes takes place in a few inches of depth. In such cases, MAGNAGHI's frame would be of no service.

Using a small boat, as I had frequently occasion to do, it is possible for the observer alone—with a boatman to keep the vessel in position—to work a 120-fathom line, and read the thermometers quite satisfactorily. It is convenient in such a case to use only two thermometers. The first is set and placed a few feet above the lead, which may be very light in still water, but must be heavy if there is a current, then lowered over the side, and the second thermometer attached 5 or 10 fathoms or feet, as the case may be, above the first. The second thermometer is set, and a messenger, previously clasped on the line, hung to it by a wire or cord, the whole being then lowered to the proper depth. The line is secured, and the interval of exposure may be taken advantage of for observing the air-temperature, at first with the dry-bulb sling-thermometer, if rain is not falling, then with the wet. Three minutes having elapsed, a messenger is clasped on the line and let go; the impact is distinctly felt in a few seconds, and that of the second messenger, released by the stroke of the first, is felt a little later. The line may then be hauled up, the thermometers placed upright in the boat without being detached from the line, then read carefully, set, and lowered again to different depths.

On the "Medusa," on which most of the observations on the Clyde Sea Area were made, the arrangements for taking soundings were convenient to the verge of luxury. A hemp sounding-line, marked with coloured worsted at every five fathoms (and at every fathom for the first ten), was coiled on a drum and passed through leading blocks to a tail block on a derrick, which projected slightly over the port side near the bow, at a height of 8 feet from the deck. The ship was stopped, and one man stationed at the wheel, with the engine reversing-gear within reach, kept her head to the sea with the line as nearly perpendicular as possible on the windward side, so that the vessel could not drift over the line. A slip water-bottle was fixed on the line, just above the lead; two feet above that—so as to be one fathom off the bottom—a thermometer was clamped on and a messenger hung to it, in order to ultimately close the water-bottle. The whole was then lowered ten fathoms, another thermometer and messenger attached, the process repeated once, or twice if four thermometers were available, and the line was lowered until the lead touched the bottom. In calm weather it was allowed to remain thus; but when there was any sea on, the depth was recorded, and the line raised one or two fathoms, to prevent bumping. A messenger was let go after three minutes; and as soon as the impact of the last messenger on the water-bottle was felt, the steam winch rapidly hove up the line. As each thermometer appeared it was removed, the winch being stopped a moment for this purpose; the reading could always be made and recorded by the time the next

instrument came to the surface. When the water-bottle was emptied, the thermometers were replaced in the same order as before, sent down to a different depth, and the process repeated again and again, until an observation had been made at every ten fathoms from surface to bottom. Then the figures, recorded by an assistant in the observation-book, were examined, and if there was any sudden difference between two, or any unusually close agreement, readings were made at intermediate depths, and this process of subdividing spaces was carried on until the exact form of the temperature curve had been ascertained. With a crew of three men it was possible, in quarter of an hour, to make and record six observations; that is to say, two dips of the sounding-line with three thermometers, and also to observe the air temperature, barometer, wind, weather, &c. This may be contrasted with the time required to get the same number of observations with spirit thermometers.

The rate of descent of the brass messengers was measured several times. Thermometers were fixed on the line at intervals of ten fathoms, and when they had acquired the temperature of the water a messenger was dropped. The time when it struck the surface of the water was noted by the seconds hand of a watch, and an assistant with his hand on the line said "one," "two," or "three," as the respective shocks caused by the impact of successive messengers, which were released by the reversing thermometers, were felt. The instant of hearing these words was also entered. This method was only roughly accurate. The time-intervals between successive shocks included not only the duration of falling of the weight, but the time which each thermometer when struck required to turn through rather more than a right angle (probably about 120°), before the loop holding the messenger slipped, and also the time during which the vibration passed up the line. These intervals were, however, practically constant in the slight depths in which observations were made. The following table (Table I.) summarises the experiments made in this way, and shows the rate of fall of the messenger in sea-water (average density, 1·0250), the figures being reduced in the last column to feet per second, the space marked as "ten fathoms" on the sounding-line having, at the time the observations were made, become equal to 62 feet, in consequence of stretching.

TABLE I.—*Mean Velocity of Fall of Brass Weights in Sea Water.*

Length of Run. Fathoms.	Average Length of Run. Fathoms.	Number of Cases.	Seconds in Falling 10 Fathoms.	Average Velocity. Feet per second.
2 to 5	3	15	8·7	7·1
6 to 9	7	4	8·0	7·8
10	10	42	7·16	8·6
13 to 16	14	4	6·9	9·0
21 to 34	27	5	6·4	9·7
38 to 64	50	5	6·2	10·0

This shows that the resistance of the water rapidly causes the acceleration of a falling weight to approach a limiting value; and from the form of the curve, which expresses the

above figures, it appears that the limiting velocity does not much exceed 10 feet per second for any depth, supposing the line to hang perpendicularly. In cases when the roughness of the sea prevented the impact of the messengers from being heard or felt, it was accordingly customary to allow one minute as sufficient for the descent of the messengers—the depth, practically, never exceeding 100 fathoms.

As bearing on the loss of time due to the travelling of vibrations up the line, the forty-two observations of the rate of fall for 10 fathoms were classified as in Table II., which shows that the limiting value was reached almost immediately.

TABLE II.—*Time occupied by Brass Weight in Falling Ten Fathoms through Water.*

Distance of Fall. Fathoms.	Approximate Depth of the Run of 10 Fathoms. Fathoms.	Number of Cases.	Apparent Time occupied in Falling. Seconds per 10 Fathoms.	Mean.
10	0 to 15	13	7·1	7·16
	15 to 30	13	7·2	
	30 to 60	13	7·1	
	Over 60	3	7·4	

The impact of the messenger, after even a long run in water, was not sufficient to damage the thermometer; but when a reversing thermometer was used for a surface observation, the shock of a messenger dropped 10 feet or more from the deck would be dangerous. Accordingly the thermometer at the surface was usually reversed by depressing the lever with a boat-hook, or by lowering a messenger along the sounding-line by a piece of twine.

Much of the credit for the rapid working which was possible on the "Medusa" is due to the skill and alacrity of her crew, and in particular to the constant attention of her skipper, Mr A. TURBYNE, whose unfailing good-humour made the work as pleasant as it was expeditious.

Treatment of Temperature Results.—The thermometer readings were entered in the observation-book exactly as taken, the correction for index-error being afterwards applied in a column left for that purpose. The observation-book had one page devoted to each sounding, printed headings for position, date, hour, state of weather, &c., and a line for the temperature at each fathom down to 10, then for each 2 fathoms to 20, and for each 5 fathoms to 110. The figures when corrected were published as already stated. From the corrected figures curves showing the vertical distribution of temperature at each station for each trip were drawn, the abscissæ being temperature, 5 millimetres representing one degree Fahrenheit, and the ordinates being depth, 1 millimetre representing 1 fathom. All the vertical temperature curves in the plates illustrating this paper are reproduced on this scale, the paper being divided for the sake of clearness into squares of 5 millimetres instead of 1 millimetre. The curves thus drawn fell into a certain

number of clearly-marked groups, which will be fully described in the sequel. In drawing, the various points are connected by straight lines, not by a freehand curve. The necessity of avoiding any theorising as to the form of the curve between fixed points was demonstrated by repeated observations of extraordinarily rapid changes, and even inversions of temperature gradient, producing sharp inflexions in the curve representing them. In some of the enclosed loch basins the upper part of the temperature curve was often sickle-shaped, and the lower perfectly straight—a state of matters which demanded very close observations to clearly define. It was my custom latterly to plot the temperatures roughly as the observations were made, and so see before leaving the station where it was necessary to take closer observations, in order to lay down the region of rapid change of curvature as completely as possible.

From the curves the mean temperature of the vertical column of water from surface to bottom was obtained by drawing a straight line cutting the curve so as to leave equal areas between it and the curve above and below the intersection. The centre of this line gave the mean temperature. The exact position of the line was found by repeated trials, and the areas measured by counting the millimetre squares. These determinations were checked in a number of cases selected at random, by taking the mean of each pair of contiguous observations, and so by adding these means, multiplied by the distance between respective pairs of readings, and dividing by the whole depth, getting the mean temperature as accurately as possible. The two methods gave results corresponding to one-tenth of a degree, the limit of accuracy of the component observations. After the mean temperatures of about a thousand soundings had been calculated, it was found that they could not be utilised in the manner originally intended, although in special cases they furnish interesting conclusions. The mean temperature of the layers, five fathoms deep, next the surface and the bottom, especially the former, yield results of greater importance, particularly as concerns the relation of air and water temperature. Seasonal curves showing the changes in mean temperature of the vertical columns, and thus—assuming constant salinity and specific heat—the changes in total heat at the station, were prepared from these data.

When dealing with enclosed lochs, and sometimes with the more open basins, it was convenient to draw isotherms, showing the distribution of temperature on a section of the region. The degree of exaggeration necessary in order to give the diagram sufficient breadth relative to its length varied in the different cases; but in all it was made sufficient to allow of isotherms for each degree Fahrenheit being clearly laid down. The depth at which the temperature at each whole degree occurred was obtained from the vertical curves. The chief difficulty in the case of a long section was the fact that there was often a considerable interval of time between the various soundings. As the distribution of temperature was in many cases profoundly altered by a single day of strong wind, this fact occasionally led to great irregularities in the run of the isotherms. On the whole, however, the sections give a fair idea of the total amount and general distribution of heat in the water. In order to allow the distribution of temperature

to appeal directly to the eye, the sections were coloured in accordance with the principle that the merging of one temperature into another should be represented by the corresponding merging of shades or colours. The coldest water was represented in purple, and at intervals of 2° dark-blue, light-blue, blue-green, green, yellow-green, yellow, orange, and deepening shades of red were employed, so that the increasing warmth of the colour corresponded in the order of the spectrum with the increasing warmth of the water. All the sections were drawn on paper ruled in millimetre squares, and by counting the number of squares between successive pairs of isotherms the mean temperature of the whole section was readily calculated.

In the case of a loch, however, the really interesting datum to secure is the mean temperature at a given time of the whole mass of water, and this was arrived at by the following method:—The mean temperature of each zone of 10 or 15 fathoms was ascertained by the process of counting squares between the isotherms crossing the zone, and the figure so secured was multiplied by a factor which took account of the mass of water in that zone. Thus the 10 fathoms of water next the surface spreads over a much greater mean superficial area than the next horizontal slice of 10 fathoms, and the lowest zone of ten fathoms has a very small mean area indeed. Thus, if fig. 1 (Plate XXII.) be an average transverse section of a loch, the mean temperatures of successive zones of 10 fathoms of which have been ascertained in the longitudinal section, and the lines a, b, c, &c., being the length of the side of the rectangle, having the same area as the section cut off between successive depths of 10 fathoms, the mean temperature M of the whole loch would be represented by

$$\mathrm{M}=\frac{m_1a+m_2b+m_3c+m_4d+\ldots}{a+b+c+d+\ldots}$$

where m_1, m_2, &c., are the successive mean temperatues of the longitudinal zones of 10 fathoms. This assumes that the isothermal surfaces are horizontal, which is not strictly true. From the few cases of observations which allowed of the construction of transverse sections showing isotherms, it appears that the isothermal surfaces are normally slightly arched in the centre, and when disturbed by transverse winds they are tilted up on one side nearly to the same degree as they are tilted down on the other, thus leaving the mean thermal condition identical with that expressed by isothermal surfaces drawn horizontally through the central soundings. In calculating thermal changes, all data are referred to half tide, as it was found impossible, from the observations available, to distinguish tidal disturbances from the other periodic phenomena. In the case of the Channel and Great Plateau, which may be looked on as bodies of water of practically uniform thickness throughout, the average temperature of the mass is given sufficiently closely by the average of the mean temperatures of the various vertical curves.

Another very instructive method of discussion of vertical distribution of temperature is to construct diagrams showing thermal change in depth and time at some particular station. Time is marked as abscissæ, depth as ordinates, and the isotherms of each

degree, or occasionally each half degree, are inserted; the spaces between being coloured as in the vertical sections. By this means the depth to which any particular temperature penetrates, and the date at which it reaches that depth, are shown at a glance. The completeness of such a diagram obviously depends on the frequency with which observations were made, and the coincidence of the periods of maximum and minimum penetration with a date of observation. Characteristic deep-water stations were selected for this treatment, including the Channel, Skate Island, and Garroch Head in the Arran Basin, Gantock and Dog Rock in the Dunoon Basin, Stuckbeg in Loch Goil, Strachur in Loch Fyne, and Shandon in the Gareloch.

The rate of seasonal descent of the maximum temperature was worked out from these sections and exhibited in the form of a curve. Special functions of temperature-change were selected for graphic treatment in certain cases, and these will be described in their proper place.

The regional distribution of temperature was worked out for each cruise by the use of charts, on which the temperature at the surface, at 5, 15, 30, and 50 fathoms, as ascertained from the vertical curves, were laid down. These charts, however, it has not been considered necessary to publish, two specimens only being given.

Terminology Employed.—In order to refer concisely to the different temperature conditions indicated by curves and sections, it is necessary to define certain expressions which I venture to use with special meanings. A mass of water at uniform temperature throughout is termed *homothermic*, and the curve of vertical temperature corresponding to this condition (a straight vertical line) is called a homothermic curve. Similarly, a mass of water, the temperature of which varies from point to point, is said to be *heterothermic*, and the corresponding curve expressing vertical distribution of temperature at any point is called a heterothermic curve. The heterothermicity of a mass of water from surface to bottom (this direction is the only one here considered) may be of several kinds, each typical arrangement giving a curve of special character. Thus, when the temperature is highest on the surface and lowest at the bottom, the prevailing character in summer, the resulting curve is said to have *positive slope;* when the temperature is lowest at the surface and highest at the bottom, the curve is said to have *negative slope.* The *slope* of a curve is arbitrarily measured by the difference between the mean temperature of the superficial layer of five fathoms and that of the bottom layer of five fathoms. It is thus practically the same as vertical range of temperature between these 5-fathom layers. When the curve is of one curvature throughout, it may be (1) *straight* when the rate of change is uniform all the way from surface to bottom; (2) *paraboloid* when the rate of change is greatest in the superficial layers, and diminishes downward; and (3) *inverted* when the rate of change of temperature becomes greater as the depth increases. These typical curves frequently occur in combination: thus a large mass of water may be homothermic, while an upper or lower layer may exhibit any one of the varieties of heterothermicity. Of these mixed types, two at least may be mentioned—the

positive or negative *S-shaped* curve, and the positive or negative *sickle-shaped* curve. The *contorted* curve, as the extreme case of heterothermicity representing superimposed layers of water at different temperatures, may also be mentioned. Examples of these are given in fig. 3 (Plate XXII.).

Air Temperature.—For the distribution of air-temperature I depend on the data supplied by Dr BUCHAN, which are published in Part I. The air-temperature observations, made by a sling thermometer at the time of each temperature-sounding, are of course affected by the diurnal range to an enormously greater degree than is the water-temperature. It is therefore impossible to apply them in any general way. Table III. gives an approximation to the mean air-temperature of the Clyde Sea Area for the three years under observation, by combining observations from selected stations; and the results are shown graphically compared with the long period mean (1866–1885), by the curve, fig. 2, Plate XXII. In this and other curves of seasonal variation the mean value for the month is placed on the line indicating the central day of that month.

TABLE III.—*Mean Temperature of Air over Clyde Sea Area.*

1886.

Station.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Glasgow, . . .	34·6	34·8	38·6	44·4	48·8	54·2	57·6	57·0	52·8	50·4	44·4	34·0	46·0
Helensburgh, . .	36·8	36·5	38·2	44·0	48·2	54·4	57·8	56·8	52·7	51·1	45·4	36·3	46·5
Dumbarton, . .	35·2	34·8	37·6	44·4	48·0	54·3	57·8	56·3	53·2	50·3	43·2	33·8	45·7
Greenock, . . .	35·4	34·8	37·4	43·2	47·2	53·4	56·8	56·7	53·0	50·3	44·2	35·0	45·6
Rothesay, . . .	36·0	36·6	39·0	45·0	47·8	53·9	56·6	56·2	53·5	51·1	45·0	36·0	46·4
Lamlash, . . .	39·4	37·1	38·0	44·0	47·6	53·2	56·1	55·9	53·8	51·0	46·5	38·6	46·8
Pladda, . . .	37·0	38·3	38·0	44·1	47·4	52·1	55·7	55·6	53·6	51·7	46·3	38·0	46·5
Mean, . .	36·3	36·1	38·1	44·2	47·9	53·6	56·9	56·4	53·2	50·8	45·0	36·0	46·2

1887.

Glasgow, . . .	38·9	40·0	39·4	43·5	51·1	58·9	60·1	57·4	52·6	45·1	40·4	37·3	47·1
Helensburgh, . .	37·5	39·3	37·8	41·7	48·4	58·0	60·0	57·0	52·0	43·6	39·4	35·8	45·9
Dumbarton, . .	38·1	40·0	38·8	43·1	50·1	58·4	60·3	57·1	52·2	45·3	41·5	37·0	46·8
Greenock, . . .	38·8	40·0	38·7	43·0	49·7	58·8	61·0	57·1	52·4	45·5	40·8	37·3	46·9
Rothesay, . . .	39·0	41·7	40·0	43·8	50·6	58·4	59·4	57·1	53·2	46·1	41·8	37·6	47·4
Lamlash, . . .	40·6	41·7	40·1	42·9	49·6	58·7	58·7	57·2	52·4	46·2	43·1	39·3	47·5
Pladda, . . .	40·5	41·6	40·7	43·2	49·9	58·8	58·9	57·4	53·1	46·3	42·2	38·8	47·6
Mean, . .	39·1	40·6	39·4	43·0	49·9	58·6	59·8	57·2	52·6	45·4	41·3	37·6	47·0

Note.—Figures in this type—47·3—are approximate only.

TABLE III.—*continued.*

1888.

Station.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Glasgow, . . .	39·8	37·0	37·1	43·2	50·3	54·1	55·6	56·2	52·8	48·4	44·2	42·2	46·7
Helensburgh, . .	38·6	38·3	38·2	44·4	50·3	54·9	55·4	56·5	53·9	49·2	45·1	42·6	47·3
Dumbarton, . .	39·8	36·3	36·3	43·0	49·5	54·0	55·3	56·3	52·7	47·5	44·4	41·0	46·3
Greenock, . .	39·7	36·2	36·5	42·9	49·5	53·5	54·5	56·4	53·0	47·8	44·4	41·8	46·3
Rothesay, . . .	40·9	37·7	37·7	43·8	49·8	54·5	55·1	55·8	53·1	48·2	44·2	42·3	46·9
Lamlash, . . .	41·2	38·1	37·6	42·4	49·1	52·8	54·2	55·0	52·2	48·0	44·2	44·0	46·6
Pladda, . . .	42·2	37·9	37·5	42·5	49·0	53·0	54·6	55·6	52·4	48·1	43·6	43·8	46·7
Mean, . .	40·3	37·4	37·3	43·2	49·6	53·8	55·0	56·0	52·9	48·2	44·2	42·5	46·7
PERIOD 1866–85.													
Mean, . .	39·4	39·9	40·6	45·0	49·5	55·1	57·7	57·8	53·8	47·6	42·1	39·4	47·3

Note.—Figures in this type—47·3—are approximate only.

Temperature Trips.

The general arrangements and routine of the trips in the Clyde Sea Area made in the "Medusa" have already been explained in Part II. p. 674 *et seq.*, and the temperature observations which form the basis of this part of the discussion were made simultaneously with the collection of samples of water for the determination of salinity.

Temperature observations were the more comprehensive in two ways. They were made at a few additional stations, and they were continued at somewhat irregular intervals for more than a year after the salinity observations had been stopped. With the exception of the trips for August 1886 and August 1887, all the thermometer readings up to September 1887 were made by myself personally. After that date they were made by Dr MURRAY or his assistants. The serial observations off Garroch Head intermediate between the regular trips were made by Mr TURBYNE.

The following list gives the number of separate temperature soundings made at each station, the date of the first and last observation, and, where the data have not been already given in Part II., the position at which observations were made. In addition, surface-temperature was frequently observed at special points, particulars of which will be given in their proper place. The occasional observations made before 1886 are not taken into account here.

TABLE IV.—*Stations where Observations of Temperature were made.*

Division and Station.	Depth. Fathoms.	Position.	No. of Obs.	Date of Observations. First.	Date of Observations. Last.
GARELOCH—					
Garelochhead,	10	See Pt. II. p. 674.	20	13.4.86	6.9.88
Shandon,	21	,,	23	,,	25.10.88
Row II.,	23	,,	15	,,	6.9.88
Row I.,	12	,,	14	,,	,,
Various,	...	...	9	...	...
LOCH GOIL—					
Lochgoilhead,	27	See Pt. II. p. 674.	16	17.6.86	3.9.88
Stuckbeg,	40	,,	21	13.4.86	23.10.88
Carrick Castle,	20	Carrick Castle, W. $\frac{1}{3}$ mile.	2	25.3.87	29.9.87
Mouth,	8	Carrick Castle, N.W. $\frac{1}{2}$ N. $\frac{5}{6}$ mile.	9	5.8.86	10.2.88
LOCH LONG—					
Arrochar,	10	See Pt. II. p. 674.	23	13.4.86	3.9.88
Thornbank,	35	,,	16	17.6.86	23.10.88
Knap,	25	Mid-channel off Knap Point.	2	5.8.86	21.9.88
HOLY LOCH—					
Head,	5	Kilmun Pier, E. by S. $\frac{1}{3}$ mile.	8	14.4.86	8.8.87
Kilmun,	10	See Pt. II. p. 674.	8	12.2.87	8.9.88
Mouth,	15	Strone Point, E. by N. $\frac{1}{4}$ N. $\frac{1}{3}$ mile.	6	16.6.86	10.2.88
LOCH STRIVAN AND BUTE PLATEAU—					
Loch Strivan Head,	12	See Pt. II. p. 675.	20	14.4.86	20.10.88
Clapochlar,	40	,,	24	,,	,,
Mouth,	34	Strone Point, E.N.E. $\frac{1}{2}$ mile.	12	18.6.86	20.9.88
Various,	...	...	11	...	...
Rothesay Bay,	12	Rothesay Pier, S.W. $\frac{1}{4}$ mile.	3	15.4.86	27.12.86
Bogany,	27	See Pt. II. p. 675.	19	14.4.86	8.9.88
KYLES OF BUTE—					
Strone Cotes,	20	,,	17	21.4.86	20.9.88
Burnt Islands ("Angle"),	28	,,	18	20.4.86	,,
Ormidale (Loch Ridun),	10	,,	16	,,	,,
LOCH FYNE—					
Cuill,	15	,,	21	20.4.86	17.10.88
Dunderawe,	35	,,	23	,,	,,
Inveraray,	60	,,	31	19.4.86	3.9.89
Strachur,	75	,,	27	20.4.86	18.10.88
Furnace,	35	,,	20	19.4.86	16.10.88
Paddy Rock,	18	Paddy Rock, E.S.E. 2 cables.	8	29.3.87	,,
Minard,	10	Minard Castle, S.W. by W. $\frac{1}{2}$ mile.	3	5.2.87	10.5.87
Gortans,	30	See Pt. II. p. 675.	21	19.4.86	16.10.88
Otter II.,	20	,,	11	10.8.86	16.10.88
DUNOON BASIN—					
Dog Rock,	50	,,	19	13.4.86	3.9.88
Coulport,	42	,,	18	14.4.86	,,
Blairmore,	35	Blairmore, W., 8 cables.	9	24.9.86	24.10.88
Strone Point,	30	See Pt. II. p. 675.	15	13.4.86	8.9.88
Gantock,	55	,,	22	14.4.86	,,
Cloch,	46	Cloch Light, S.E. by E. $\frac{1}{2}$ E. $\frac{1}{2}$ mile.	3	5.8.86	22.9.88
Wemyss,	43	Wemyss Pt., S.E. by E. $\frac{1}{2}$ E. $\frac{1}{2}$ mile.	2	6.8.86	23.9.86
Knock,	40	See Pt. II. p. 675.	13	,,	25.10.88
Various,	...	...	2	...	...

TABLE IV.—*continued.*

Division and Station.	Depth. Fathoms.	Position.	No. of Obs.	Date of Observations.	
				First.	Last.
ARRAN BASIN—CENTRAL—					
Otter L.,	30	See Pt. II. p. 675.	13	19.4.86	28.9.87
Kilfinan,	85	Otter House, E.S.E. 2¼ miles.	12	29.3.87	19.10.88
Skate Island,	107	See Pt. II. p. 675.	32	27.3.86	19.10.88
Ardlamont,	30	,,	16	20.4.86	20.9.88
Inchmarnoch,	88	,,	12	9.6.86	15.2.88
ARRAN BASIN—EASTERN—					
Garroch Head,	60	,,	40	17.4.86	29.10.88
Brodick,	90	,,	20	15.4.86	19.8.88
Lamlash,	14	Lamlash Pier, N.W. 6 cables.	5	17.4.86	31.3.87
Largybeg (and near it),	60	See Pt. II. p. 675.	10	12.8.86	10.12.87
Various,	...	...	2	...	...
ARRAN BASIN—WESTERN—					
Off Loch Ranza,	70	L. Ranza Castle, S. by E. ½ E. 1½ mls.	10	9.2.87	5.2.88
Carradale,	80	See Pt. II. p. 675.	22	19.6.86	22.3.88
Ross Island,	45	Ross Island, W. 1¾ miles.	3	9.12.87	20.3.88
Davaar,	30	Davaar Light, W. 1¾ miles.	3	18.6.87	22.9.87
Various,	...	...	5	...	...
GREAT PLATEAU—					
North-west,	22	See Pt. II. p. 675.	43	16.4.86	20.1.88
Southern,	27	,,	21	,,	20.1.88
Campbeltown Loch,	8	Off shipyard, mid-channel.	6	18.4.86	8.3.88
CHANNEL—					
Sanda,	40 to 60	See Pt. II. p. 675.	8	16.4.86	21.3.88
Deas Point,	50	Deas Point, N. 1½ mile.	3	19.6.86	17.3.88
Cantyre,	60	Mull of Cantyre Light, N. by E. 2½ miles.	5	16.4.86	31.3.88
Various,	...	...	2	...	...

The work to be reviewed comprises 900 temperature soundings, or not less than 6000 separate thermometer readings, taken at about 75 stations during a little more than three years. In that time 23 separate temperature trips were made, in each of which the whole Area was gone over with some approach to completeness, and there were several occasional observations between these trips. Vertical temperature sections for sixteen of these trips from the Channel to Cuill are given in Plates VIII. to XI.

Trip I., April 1886 (See Part II. pp. 677–678).—The early months of 1886 were characterised by low air-temperatures over the whole Area, the temperature for January, February, and March averaging more than 2° below the normal for that time of year. A preliminary observation at Skate Island on March 27 gave an average mean temperature of 41°·3 for the vertical section; and as on April 19 the mean was 41°·6, it would appear that the minimum mean temperature occurred in March, and that there had been very little heating during the earlier

part of April. On this trip, indeed, the temperature at every part of the Area was lower than on any subsequent occasion in the whole period during which observations were carried on. Observations were made from the 13th to the 21st, omitting the 18th, and the prevailing character of the whole region from the Channel to the loch-heads was uniformity. The surface temperature indeed varied a few degrees, averaging about 44°·5 for all parts except the Channel and Loch Fyne (from Otter to Strachur), where it was about 42°·5. The surface water formed a thin layer: at 15 fathoms the average temperature was about 41°·5 for all parts except the Channel and Loch Fyne, where it was about 42°, and this distribution held good to the bottom. Between 10 or 15 fathoms and the bottom there was not in any part a greater variation than 0°·2. The mass of the water in the Gareloch and Loch Long had the temperature 41°·8, which may be taken as typical of the lochs and basins. Loch Fyne, however, had the mean temperature of 42°·0, and so also had the Channel. This difference of temperature, although small, is significant. It shows that the Area, as a whole, had cooled down more than the open water of the Channel, influenced by the Gulf Stream, and more than the doubly enclosed water of Loch Fyne, which had not lost the whole of its previous summer's increment of heat.

The prevailing winds for some time previously had been northerly and north-easterly: the conditions during the trip were anticyclonic. The result was in almost every case a down-loch wind, which was strongly felt in Loch Fyne and Loch Strivan. The observations of density showed evidence of upwelling at the head of all the lochs, and this was confirmed by the temperature sections for Loch Fyne and Gareloch, in both of which the isotherms had a definite seaward dip, showing upwelling of cooler water from below.

The mean temperature of each sounding, the surface-temperature, and the temperature at 30 fathoms are shown on map 1 in Plate XXI. as a type of temperature distribution at the spring minimum.

During the trip there was a comparatively rapid heating of the water in progress, observations on the Gareloch on the 13th and 21st showing a gain of from 2° to 3°.

The seaward reaches of the Firth of Forth were practically at the same temperature, averaging 41°·5, as ascertained by a trip from Granton to the Isle of May on April 23rd.

Trip II., June 1886.—The central day of this trip was sixty-one days after the central day of Trip I. In the interval the curve of air-temperature was parallel to the long period mean, but at least 1°·5 lower. The winds had been prevailingly northerly. During the trip (June 16–22) the wind changed to north-west and west, and at times blew strongly. There was bright sunshine most of the time, contrasting with the weather of the previous six weeks, when there was a marked lack of sunshine.

In Loch Goil and Loch Strivan there were strong down-loch winds during observations; in Loch Fyne the wind was blowing freshly up the loch, and in Loch Long and the Gareloch the wind was transverse, from the west. Rapid heating had taken place everywhere on the surface, especially in the seaward division; the

surface temperature was over 50° everywhere south of Bute, but nowhere reached that figure to the north of it. In the Channel, indeed, the surface temperature was somewhat lower, although that at the bottom was higher, than inside the Great Plateau. The general condition may be expressed by saying that the water was growing rapidly warmer from the surface downward and from the ocean inward. Warming from the ocean was evidently in progress, by the tide drawing inward over the great counter of the Plateau slices of water from the mass, at uniform temperature of over 47°, outside; this was chilling the surface layers, but, in virtue of its superior salinity, warming the lower layers. That this was the case was shown by the rapid seaward slope of the isotherms in vertical sections of both branches of the Arran Basin. The warming had proceeded to the greatest depth just inside the Great Plateau, where 46° was found at 30 fathoms, and its influence gradually diminished landward, until at Otter the isotherm of 40° reached the surface, and at Gantock rose to 6 fathoms. Solar surface-heating was most marked in the East Arran Basin. The influence of configuration was very beautifully brought out in the deep basins of Loch Goil and Loch Fyne. The bottom at Stuckbeg had the temperature 41°·9, a rise of only half a degree since April, while in Loch Fyne the very remarkable phenomenon of a mass of cold water sandwiched between warmer layers was observed.

The mass of water at uniform temperature, which made the lower part of all the curves of vertical temperature in April perpendicular lines, was no longer found. There was everywhere (Upper Loch Fyne excepted) a positive slope in the curve, showing continuous, though not uniform, warming from the surface downward. In this trip the salinity observations showed, much better than the temperature, the effect of wind in setting up vertical circulation.

Trip III., August 1886.—The observations (by Mr J. T. Morrison) were made in two parts, the first from August 3rd to 7th inclusive, the second from the 10th to the 13th. The interval between this trip and that of June was fifty days. The weather of this period showed air-temperatures rather less than a degree below the average for the season; the first and last week of July were hot, but the middle fortnight colder, and the early part of August nearly came up to its normal warmth. The prevailing wind had been south-westerly. During the trip the weather was broken, several small cyclones passing and producing variable light winds, usually from the south-west, and blowing up most of the lochs.

The distribution of temperature was practically the same as in June, although the water was, throughout, warmer. In the North Channel the whole mass of oceanic water, remaining homothermic, had warmed up to 52°·7, and pouring over the Great Plateau, as in June, cooled the upper and warmed the lower layers in the Arran Basin. The isotherms on the sections from Channel to loch-heads dipped, as before, strongly seaward. As before, the water in the deeper parts of the Arran Basin had warmed more slowly than that outside, and remained colder, being 46° at 50 fathoms,

where the Channel was 52°·5. And, as before, the deep isolated loch-basins retained still colder water, the minimum temperature being 43° in Loch Fyne. The minimum there occurred, as in June, about half way between surface and bottom, the vertical curves being sickle-shaped. The maximum effect of sun-heating was shown near the head of the lochs and in the southern branches of the Arran Basin.

During this period the temperature in the North Sea, off the mouth of the Firth of Forth, was about 52° from surface to bottom, more than a degree colder than off the mouth of the Clyde Sea Area.

From August 24th to 30th a short trip was taken in the Dunoon Basin and Loch Fyne, and a few observations were also made in the Arran Basin and Loch Fyne from September 13th to 17th. The data obtained fall into their natural places in discussing the separate stations and regions. They served to fix the period of surface maximum temperature for the year, but are not otherwise of general interest.

Trip IV., September 1886.—The general climatic conditions of this trip, lasting from the 22d to the 27th, are given in Part II. p. 680. It occurred forty-eight days later than Trip III. Air-temperature was a little below the normal during August and September, and the weather was fine on the whole, although rather rainier than the average. From September 10th to 22d an anticyclone prevailed, with very light airs, and during the greater part of the trip there was a calm. A cyclone passing from the 25th to the 27th brought a fresh westerly breeze, blowing transversely to the Central Arran Basin and Loch Goil while these regions were being examined. This trip may be said to have been taken at the period of the annual maximum: the maximum for the surface water was past, and cooling had just commenced, but the maximum of the deeper layers was not yet reached. The oceanic water was still the warmest, a fact that was very clearly ascertained, as a larger vessel than the "Medusa" was available, and soundings were made well out in the North Channel, south of the Mull of Cantyre and across toward the Galloway coast. The Channel was filled with water at the uniform temperature of 54°·5, and from the Channel inward the temperature diminished. The coldest water in the Arran Basin was a little under 48°, and occurred at the bottom off Skate Island. The same temperature was reached at 15 fathoms in Loch Goil, where the bottom temperature sank to 44°·3, and at 25 fathoms in Loch Fyne, where the bottom was slightly under 44°. These deep lochs had thus kept their water more than 4° colder than the open basins, and more than 10° colder than the open sea. On this occasion the surface water was everywhere warmest, and the bottom water coldest, all indications of an intermediate minimum having vanished from Loch Fyne.

It should, of course, be remembered that practically all the observing stations were midway between the coasts of the various natural regions examined, so that the effects of local heating on a shallow shore were not observed. This effect is, however, considerable, and in some places may materially raise the temperature of the shallow water, but the broad inrush with every tide of the uniformly heated water from the Channel is unquestionably the most important factor in raising the temperature for the year. That its

influence is greater than that of solar radiation is perfectly shown by the very much slower rate of warming in the masses of water cut off from free communication with the ocean, but more exposed in every way to solar power from the much greater influence on their waters of the heated land and warm surface drainage.

The process of heating-up from a practically uniform coldness in all parts of the Area has so far brought out month by month with increasing distinctness the enormous power of physical configuration in dominating thermal changes,—none the less because the process of heating-up was probably retarded on account of the abnormal coldness of the whole spring and summer. The average temperature of each vertical sounding, the surface temperature, and the temperature at 30 fathoms are given on map 2, Plate XXI., as a typical example of the distribution of warmth at the autumn maximum.

Trip V., November 1886.—This trip, fifty-two days later than that of September, occupied the time from November 11th to 18th, excluding the 14th. It commenced to take account of the cooling-down consequent on the excess of radiation from the surface after sunset over the radiation to the surface during day-light. The typical character of the observations was rather spoiled by the exceptional warmth of the air in October and November, the mean of each month being about three degrees above the average. This was particularly the case in the landward portion. The rainfall of October was much below the average. Easterly winds were common, with frequent storms, and the weather, although unusually bright, was disturbed. From November 1st to 4th there were strong south-westerly and westerly winds. The early part of the cruise was favoured with fine weather, calm and showery, with snow on the hills. The landward portion, Loch Fyne excepted, was examined in these conditions. On the 14th, when no work was done, there was a south-westerly gale; on the 15th the Kyles of Bute and East Arran Basin were worked in a stiff south-westerly breeze. The 16th and 17th were squally, and on these days the West Arran Basin and Loch Fyne were visited. The 18th being calm, though hazy, was devoted to the Great Plateau, and on the 19th work was stopped by a gale from the south-west.

Surface-cooling was in progress everywhere. The whole mass of water beyond the Plateau had cooled down to about 50°·5, but was still warm enough to exercise a distinctly warming action on the deep water of the southern end of the Arran Basin, although the surface of that basin had cooled to a lower temperature. Excluding the extreme instances of highland isolation, Lochs Goil and Fyne, the average temperature of the Area at the surface was 49°·5, and at the bottom 51°·5. Thus while the whole of the shallow water and of the Dunoon Basin had cooled down from three to six degrees since September, in the Arran Basin the temperature at 25 fathoms was the same as during Trip IV., and below that depth there had been a marked heating. The slope of the curves of vertical temperature had, in fact, been inverted, and assumed the negative or winter form, the maximum temperature being at or near the bottom.

In Loch Fyne and Loch Goil surface-chilling had set in strongly, but the bottom water remained cold (44°·5 to 45°·5), and the result was a warm intermediate layer,

losing heat upward to meet the coming winter's cold, and passing on heat downward to neutralise the cold of the past winter, which had remained as in an ice-house all summer under the ill-conducting blanket of water cut off from free circulation.

Trip VI., December 1886.—Forty-one days separated the middle of Trip V. from that which lasted from the 22nd to the 30th of December. The exceptional warmth of November had given place to an exceptionally cold December, the mean temperature of the air over the Area being 3° below the average. The latter part of November had been wet and stormy, and December also had the usual character of a West Coast winter month, with strong variable winds and much rain. During the trip every kind of weather was experienced. Loch Long, Loch Goil, and the upper part of the Dunoon Basin were studied on the 22nd, with a fresh northerly breeze and heavy rain; the rest of the Dunoon Basin and Loch Strivan on the 23rd, with light varying airs. On the 24th in West Arran Basin a stiff breeze blew from the N.W., and on the 25th on the Great Plateau and Channel a gale sprang up from the S.W. On the 26th and 27th the Arran Basin was worked through in calm haze with snow-showers, on the 28th a westerly gale with heavy squalls drove the "Medusa" into the Gareloch, and the 29th and 30th allowed Loch Fyne to be examined in bright, calm weather, the hills snow-clad, and the surface of the loch in some places coated with ice. The distribution of the ice and its physical conditions have been already described (see Part II. p. 681). Under the ice, at the depth of 2 inches, the temperature was 35°·9, and at 6 inches 41°, showing the extreme thinness of the cold upper layer.

During this trip the temperature of the air was much lower than that of the water, and a number of curious mirage-effects were observed, the Irish coast appearing elevated above the water, and steamers seeming to be pursuing their course underneath the land. The well-known appearance of Ailsa Craig as a mushroom was also clearly seen. Cooling had gone on steadily from the surface throughout, but, except near the heads of lochs and in shallow water, the surface warmth ranged between 45° and 47°, the lower layer being everywhere warmer, and in the open basins the maximum occurred at the bottom. In Loch Fyne the bottom cold layer was thinned down, but had not disappeared, and Loch Goil showed the same effect in a less prominent way. In the North Channel the water was warmer than anywhere else, 48°·5 from surface to bottom, but the effect of surface-cooling made itself felt on the Great Plateau and in the whole of the rest of the Area. It is evident that the influence of the tide is a warming one, even in December, the ebb carrying out the cold surface water, and the flood carrying in warmer oceanic water.

Trip VII., February 1887.—Observations were made between the 3rd and 12th, excluding the 6th, and the trip was forty-three days after that of December. Air-temperature during January had been close to the average for that month, and in February it was decidedly higher, although in the latter month there was a good deal of snow on the surrounding land. The weather in the earlier part of the cruise was under the influence of a cyclone producing strong winds from the west on the 1st, south on the

2nd and 3rd, south-west on the 4th and 5th, when Loch Fyne was examined during an up-loch wind. On the 7th, Loch Strivan was visited during a stiff south-easterly breeze blowing right up the loch. The rest of the trip took place in anticyclonic conditions, clear skies and hard frost prevailing with low-lying mist over the water, which greatly impeded the work, making it impossible to attempt observations in the Channel. Thin ice was floating along the shore of the Dunoon Basin, from Hunter's Quay to Toward, at the head of Loch Long, and in particular in Loch Goil, where the observations had in consequence to be reduced in number. The surface water necessarily varied greatly in temperature on account of the rapid and frequent changes of weather, but it was always coldest, and below 5 fathoms the water was almost homothermic in all parts except Loch Fyne and Loch Long. The mass of the water in the Area had a temperature not varying half a degree from 44°. The distribution of warmth was unusual, since for the first time it appeared that the water on the Great Plateau was, throughout, colder than that in the Arran Basin. This apparent anomaly may be partly explained by the fact that no observations were obtained in the Channel, but the distribution is confirmed by the observations near the head of the various basins, where at all depths water somewhat warmer than that near the Plateau was found. This seems to indicate that the cooling by radiation of the Sea Area had slackened, and that the Channel water being now slightly colder than that inside, was rapidly lowering the temperature of the seaward division by tidal interchange. Loch Goil, where the maximum temperature of the Area (47°·3) now occurred at the bottom, and Loch Fyne, where the maximum (46°·5) had not worked its way quite so far down, may have helped to maintain the higher temperature at the head of the Dunoon and Arran Basin by outflow. In Loch Strivan the very remarkable juxtaposition of two homothermic masses of water at different temperature, already referred to in describing the methods of observing (p. 5), was found. From the surface to 9 fathoms the temperature was uniformly 42°. At 9½ fathoms it was 44°, and this temperature (rising about one-tenth of a degree) was maintained to the bottom in 35 fathoms.

Trip VIII., March–April 1887.—The trip, occurring fifty days after that of February, commenced on March 25th and ended on April 3rd, no observations having been made on March 28th or April 1st and 2nd. March had been a colder month than February as regards the air. It was, indeed, almost as much below the seasonal average as February had been above it. There had been a good deal of snow. The weather of the period during which observations were made was very stormy. A passing cyclone, on the 24th and 25th, brought strong winds, shifting from south-west to north-west, blowing right down Loch Goil and the Gareloch, when they were visited. The north-west gale blew strongly on the 27th and 28th, transversely to Loch Fyne; but on the 29th and 30th, when that loch, the West Arran Basin, and Channel were worked over, it gave place to anticyclonic weather, calm and hazy. This fine spell was short-lived: a north-westerly gale commencing on the 31st kept the "Medusa" a prisoner in Lamlash Bay until April 3rd, when the final observations in the East Arran Basin were made.

This trip came nearest to the minimum for the season, but the water temperature

was neither so low nor so uniformly distributed as in April 1887. The surface water had once more commenced to warm up, especially in the seaward portion, and there was a slight fall of temperature toward the bottom. The mass of water in the Channel averaged 44°·5; in Loch Goil and the Upper Basin of Loch Fyne it was warmer, cooling having taken place very slowly. The Arran Basin had on the whole a temperature under 43°·5, and the Dunoon Basin and shallow lochs were slightly colder than this.

This trip found the Channel warming up, and almost arriving at the same degree as the deep isolated lochs which were still passing down the heat of 1886. The open basins, which had cooled more rapidly, had reached their minimum, and so, having just begun to heat up again, were colder than either the free or the nearly completely inclosed areas.

Loch Lomond and Loch Katrine, fresh water lakes, which were visited just before the Clyde trip, had the temperatures of 41°·0 and 40°·2 respectively throughout their whole depth in the deepest parts.

Trip IX., May 1887.—The observations were made forty-one days after Trip VIII., and occupied from May 6th to 11th, no work, however, being done on the 8th. In April the air-temperature had been considerably below the average for the season, and snow had often fallen; but May was, so far as regards warmth, a normal month. From May 1st to 8th the weather was calm, with light and irregular wind. On the 9th it was blowing half a gale from the west, and temperature observations were made in the West and Central Arran Basin, but the rough sea put a stop to the work. On the 10th Loch Fyne was visited with a fresh westerly breeze, blowing, on the whole, up the loch. On the 11th a light down-loch wind was found in Loch Strivan.

The surface temperature was highest in Loch Fyne and Loch Goil, both of which had cooled down in the lower layers until they were practically of the same temperature as the slightly warmed mass of the open basins outside, which below 15 fathoms of depth had a temperature of from 45°·0 to 44°·3, the West Arran Basin being somewhat warmer, probably on account of its freer communication with the open sea. In the Channel the temperature of the whole mass of water was 46°. Inside, the surface was everywhere warmer, and the water below 10 fathoms everywhere colder than this figure. As in other cases when a homothermic condition was beginning to be disturbed by surface-heating, there were several instances of intermediate maxima or minima. In Loch Fyne a very feeble indication of the kind of distribution which characterised June and August 1886 was detected, and similar anomalies were noticed on the Great Plateau, in the Arran Basin, and near the head of the Dunoon Basin. Evidently when there is no marked stratification of water due to a heterothermic condition, the disturbing effects of change of salinity would have freer play than at other seasons in determining vertical movements.

Just before this trip Dr MURRAY had made an extensive series of observations on the northern lochs of the West Coast and the fresh water lakes of the Great Glen. In a depression of 137 fathoms off Scarba, in the Atlantic, the temperature from surface to

bottom was found to be 45°·7, corresponding closely with the condition of the North Channel, the rise of 0°·3 in the interval between the two sets of observations being insignificant. Loch Linnhe, fairly open to the sea, showed a temperature of 45°·5 on the surface, a minimum of 44°·3 at 15 fathoms, and thence a rise to 44°·9 on the bottom in 50 fathoms. Loch Etive, the most completely inclosed sea-water basin on the coast of Scotland, showed in the deepest part surface water at 48°·4, a minimum of 44°·3 at 10 fathoms, and a rise to 47°·6 on the bottom, a condition very similar to that of Loch Fyne at the same period of 1886. In Loch Morar, the deepest fresh-water lake in Scotland (175 fathoms), the surface temperature averaged 43°·5, and all below 40 fathoms was constant at 42°, while in Loch Ness nearly the whole mass of the water was at 41°·5. All the observations show clearly that the more completely a deep basin is cut off from the sea, the more slowly is its water influenced by the advance of summer heat.

Trip X., June 1887.—This trip, lasting from the 13th to the 18th, was thirty-eight days later than the preceding one. The temperature of the air during June, as a whole, was 3° above the average of the season for the Clyde Sea Area, while May had been a month of average warmth. June 1887 was indeed the warmest on record, and the great anticyclone which prevailed for the first half of the month is remembered by the accident of including the days when the Queen's Jubilee was celebrated. Almost the whole cruise was carried out in intensely hot, quite windless, cloudless, but slightly hazy weather. On the 13th, however, there was a great deal of heavy rain, and on the 14th, when Loch Goil, Dunoon Basin, and Loch Strivan were examined, there were frequent drizzling showers.

Solar radiation had here a perfect opportunity for showing its utmost power, and the temperature of the surface water was naturally greatly raised. On the 16th, 17th, and 18th, the hottest days, the surface may be said to have stored, on the average, heat enough to warm it by 2° per day. At no time in the summer of 1886 were such high surface temperatures observed.

Even in the Channel the surface water was warmer than that beneath, although the range was, as it always is, less than in any other part of the Area where the depth is equal. The range was from 52°·5 to 48°, the average being almost 2°·5 warmer than in May. The Arran Basin, as a whole, had heated up about 4° throughout, and was 5° warmer than in June 1886. This was particularly noticeable in the Western Branch, where the temperature was considerably higher than in the equally deep parts of the Eastern Branch. During the cruise the increase of temperature seemed to be due rather to solar than to oceanic heating, and a prolonged series of hourly observations on the Great Plateau furnished some important suggestions as to the mechanism of the interchange of water by tidal currents. The great range between the temperature of surface and bottom water on this occasion made it peculiarly opportune for an experiment to determine the movement of the water. The deepest part of the Central Arran Basin was filled with water everywhere over 46°, except at the upper end (next Loch Fyne), where a mass of water at slightly lower temperature was found. This cold mass was

in the form of a layer extending from 25 fathoms to the bottom at Kilfinan, but thinning away until at Inchmarnoch it was only 10 fathoms thick, and surrounded above and below by warmer water, evidently influenced by the ocean. A like remnant of colder water was found in a similar position at the head of the Dunoon Basin. The deep lochs were comparatively little affected by the rapid rise of air temperature. In Loch Fyne the minimum, not quite at the bottom, was 45°, and in Loch Goil the minimum at the bottom was 44°·9. The Gareloch was, as a whole, the warmest division of the Area, but high surface temperatures were found in all the sea-lochs, the absolute maximum being 60° in Loch Long. The influence of a long spell of hot dry weather on narrow waters is obviously not confined to the incidence of solar radiation on the surface. The water flowing in from the land is heated up by trickling in shallow streams across the hot rock or sand, and this influence is evidently cumulative. The longer the hot dry weather continues, the more potent is it to raise the surface temperature of the water, the diminished influx of fresh water being more than made up for by the enhanced temperature of the affluents.

Trip XI., July 1887.—This was a short trip, confined to the West and Central Arran Basins and Loch Fyne. It only occupied three days, July 6th to 8th, and was twenty-two days later than the June trip. The weather of July, as a whole, was almost as much above the average with regard to air-temperature as that of June had been. On the cruise, each day was calm, or with very light breezes; the 6th was dull and showery, the other days bright and warm. On this occasion, in the Central Arran Basin, an effect common on all calm summer-days was exceptionally well developed. The air blowing as a gentle breeze off the land, swept across the water in hot puffs, laden with the scent of heather, which could not be perceived at all in the perfectly calm intervals between the breezes. The surface temperature of the water averaged about 56°, in Loch Fyne exceeding 60°. The water coming in from the Channel had the temperature of 56° on the surface and 50° at the bottom on the outer edge of the Great Plateau in 30 fathoms. In the West Arran Basin it was evident that this warm water was doing more than surface-heating to warm up the lower layers. The deeper layers of Loch Fyne were, as usual, the coldest, but were heating uniformly, showing none of the eccentricities of the previous summer.

In the course of this trip a number of experiments were made on the rate of descent of the brass messengers used to reverse thermometers, and on the correction to be applied to thermometers read at higher temperatures than those at which they were reversed. These results are treated of at pp. 7–8.

From July 12th until August 12th I was engaged in a special research for the Fishery Board for Scotland into the physical condition of the fishing-grounds on the north-west coasts of Scotland. I made observations on July 13th on Loch Torridon from H.M.S. "Jackal," and found the water in the lower loch to vary from 56° on the surface to 49° at 65 fathoms. In the more isolated upper loch, the surface temperature was 61°, and that at 45 fathoms 51°. On the following day, observations made in the Minch

between Loch Torridon and Stornoway gave 53°·3 for the surface, and 47°·8 at 85 fathoms. Thus although in that channel there are strong tidal currents, the typical mixing of the whole mass of the water found in the North Channel did not occur. This work was fully reported on in the Sixth Annual Report of the Fishery Board for Scotland for the year 1887, Appendix C., and a summary of the conclusions was published, under the title "Sea-Temperatures on the Continental Shelf," in the *Scottish Geographical Magazine*, iv. (1885) 544–549.

Trip XII., August 1887.—During the month of August 1887, Dr MURRAY made a series of temperature soundings in the Clyde Sea Area, from the 6th to the 9th, doing all parts except Loch Fyne, and from the 12th to the 17th, completing Loch Fyne and the Arran Basin. Viewed as one trip, this would give an interval of 35 days since the last.

The air-temperature for August was the average for that month, and thus showed a considerable falling off from July. The 6th was calm; on the afternoon of the 7th a westerly gale sprang up, shifting to north-west and blowing strongly on the 8th, and to north-east, dying away on the 9th. For the rest of the time the wind was light and variable. Rapid warming had taken place in the shallow lochs and estuary, and in every part of the Area the water-temperature was 4° or 5° higher than in August 1886. The Channel was occupied by a homothermic mass of water at 55°·3. At the same date my observations on H.M.S. "Jackal" showed that in the open Atlantic west of St Kilda the surface temperature was 57°, at 30 fathoms 55°·1, and at 100 fathoms 48°. On that occasion I found that the water of the North Atlantic was, speaking roughly, of uniform salinity, but that it consisted of three horizontal layers of different temperature. The first was a homothermic layer at 56°, extending from the surface to 25 fathoms; this was succeeded by a zone of rapid change of temperature about 15 fathoms thick, under which there was a homothermic mass of at least 60 fathoms of water at a temperature between 48° and 49°. It may not be too much to suppose that this superficial mass of warm water represents the Gulf Stream drift; at anyrate, it is certainly the warm surface water driven in toward the land by prevailing westerly wind; and as the upper homothermic zone deepens toward shore, and is stirred throughout its whole extent in passing through tide-ways, it appears that the North Channel is usually fed with surface water of the ocean, a fact which would largely serve to account for its being warmer than the Clyde Sea Area, even in summer.

On this occasion the warm water pouring across the Great Plateau was obviously at work warming the deep basins, the coldest parts of which lay at their upper ends. The Dunoon Basin showed a patch of central heating separating cooler water which lay to the north and to the south. This effect is probably accounted for by the current of warm water sweeping in at right angles from the estuary. The coldest regions were naturally the deep lochs: the bottom temperature of Loch Fyne was 45°·2, with no trace of the intermediate minimum which kept the bottom water from rising above 44°·2 a year before; that in Loch Goil was 45°·4, contrasting with 43°·1 in the previous August.

Trip XIII., September 1887.—With its central day 47 days after that of August, this trip lasted from September 20th to 30th, with the exception of the 25th, 26th, and 27th, when a break-down of the "Medusa's" machinery and other causes prevented observations from being made. This was the last trip on which I made the observations personally, and the last also on which the density of the water was determined. (Part II. pp. 684–685.)

The temperature for August had been normal over the Clyde Sea Area, and that for September about 1° below the seasonal average. The early part of September was stormy, with frequent south-westerly gales; but during the earlier part of the cruise (19th to 24th) there was an anticyclonic calm, with very light breezes and haze. The 26th and 27th were characterised by strong winds from N.W. or S.W.; the 28th, when Loch Strivan was visited, was calm, with low barometer and a northerly air; while on the 29th and 30th, the Gareloch and Dunoon Basin were studied amidst heavy squalls from the north-east.

During this trip special attention was given to the condition of the water in the East and Central Arran Basins, several cross-sections being run in order to bring out the effect of the proximity of land.

The surface water was everywhere beginning to cool, although heat was still being propagated downward in all parts of the Area. Observations by Dr MURRAY from the "Medusa" in the Sound of Mull, and off Ardnamurchan Point in the open Atlantic, showed a uniform temperature of 57°·3 from surface to bottom, where the depth exceeded 100 fathoms, on September 4th. In the Channel the average temperature throughout the whole depth was 56° on September 21st; over the Great Plateau itself it was 55°; and practically the whole mass of the Area was over 50°. The only tracts where the temperature was lower were the deep loch basins (Loch Fyne and Loch Goil) and the deepest part of the Central and Eastern Arran Basins below 60 fathoms. The deep water of the Area was at no previous time, nor on any subsequent occasion, so warm as during this trip, which may be taken as representing the maximum storage of heat. The observations early in the month on Loch Ness and Loch Morar showed that the minimum temperature at the bottom of these fresh-water lakes was 42°·1.

From October 1887 to October 1888 the "Medusa" was at work on the Clyde Sea Area or in the northern lochs almost continuously, and results of great interest were obtained in each of the separate divisions of the Area. The continuous method of working, although of the utmost service in elucidating the changes in progress in different basins (under the head of which they will be considered), was not so well adapted to bring out the general character of the Area as a whole at definite periods, separated by approximately equal intervals of time. These observations form the subject of a special discussion by Dr MURRAY on the effect of wind in producing temperature changes in sea and fresh-water lochs, published in the *Scottish Geographical Magazine* for 1888, vol. iv. p. 345. They are grouped together in what follows into a series of "trips" more or less com-

pletely covering the Area, but individually occupying a considerably longer time in doing so than was taken by the thirteen trips already touched upon.

Trip XIV., November–December 1887.—From September on to the end of the year the mean temperature of the air over the Clyde Sea Area was considerably below the average for the season, contrasting in this respect with the abnormally mild autumn and early winter of 1886, and serving to accelerate the process of cooling-down from the great warmth of the summer maximum. The trip was in two parts. The first, November 5th to 8th, was devoted to Loch Fyne. The weather was calm on the 5th; on the 7th, stormy, with a fresh breeze from the north-east blowing down the loch, and producing very marked changes of temperature; and on the 8th, a light breeze from E.S.E. The second part, from November 29th to December 10th, took account of all the remaining divisions of the Area. The first day was calm. From December 2nd to 8th the wind blew freshly or strongly from the west, south-west, or south. On the 9th and 10th it was light and northerly. At the bottom of Loch Fyne the temperature was 45°·5; at the bottom of Loch Goil 49°·4, the highest ever found there. In the Channel the water was at 49°·8, showing rapid cooling since September. Surface temperature diminished rapidly landward, and came to a minimum of 42° in Loch Goil. The surface was everywhere colder than the deeper layers, the vertical curves everywhere showing the typical negative slope of winter. The warmest water was found, curiously enough, in Loch Strivan, where all beneath 5 fathoms was at 50°·1.

Trip XV., December 1887–*January* 1888.—This trip extended from December 15th to January 8th, and during it particular attention was given to the conditions of the Upper Basin of Loch Fyne, with special reference to the influence of wind. All parts of the Area were visited. December was considerably below the average of the season with regard to air-temperature. During the cruise all varieties of weather were found. It commenced in a calm, followed by variable airs, which on the 17th developed into a heavy gale from the west and north-west, blowing across Loch Fyne. On the 18th there were heavy squalls from the north-west, but the rest of the month had only light winds. On the last day of the year, when the Great Plateau was being examined, the breeze blew fresh from the west, changing to S.S.E., and increasing in force on January 1st. The last week was characterised by light winds, usually from a southern quarter. No observations were made on this trip in the Dunoon Basin, or the lochs with which its northern end communicates.

The water of the North Channel was at 47°·3; that in the middle of Loch Fyne, although sandwiched between colder layers, remained the warmest (48°·5) in the Area, so far as the observations could show. Except in Loch Fyne, which was warmer, the temperature of the Area at five fathoms averaged 45°, and at 30 fathoms a little over 46°, showing how rapidly surface-cooling was at work. It is noticeable that, as in the previous year, the Channel temperature remained higher than that of the partially enclosed waters inside the Great Plateau.

Trip XVI., January 1888.—The month of January was, like February of the

previous year, distinctly above the average with regard to air-temperature. Only a few observations were made, and these only in the southern part of the Area, between the 18th and 20th, when light winds from east and south prevailed, on the 27th, during a heavy northerly gale, and the 30th, in a dead calm. The temperature of the few stations examined on both occasions was found to be about a degree lower than during Trip XV. Advantage was taken of the storm, on the 27th, to investigate the action of wind in Loch Strivan.

Trip XVII., February 1888.—Observations were made in the Gareloch on the 9th and 10th in heavy squalls and a prevailing north-westerly wind. From the 11th to 15th the weather was fine, with a very light northerly wind, on the 15th the wind was westerly, and on the 16th a light air from the south. On the 17th, the last day of the trip, the wind rose to a gale from the north-east. The mean air-temperature of February was fully 2°·5 lower over the Clyde Sea Area than the normal, thereby contrasting with the exceptionally mild February of 1887, and approximating to the great cold of February 1886.

In the Channel the water had a temperature of 44°·8, but for the rest of the Area the average was about 44°·3, with little change on account of depth in the more open basins. At the head of the Arran and Dunoon Basins 45°·0 was found at the bottom, but the warmest water occurred, as usual, in Loch Goil, which below 20 fathoms was within 0°·2 of 46°, and in Loch Fyne, where a well-marked intermediate maximum, over 46°, occurred between the depths of 3 and 20 fathoms.

The general condition was a reversion toward the simple arrangement of temperature, homothermic as regards both depth and surface, which is characteristic of the spring minimum. The curious fact, several times noticed before, that the whole mass of the great Arran Basin was colder than the water of the Channel or that of the enclosed lochs was again brought out, although the Channel was colder than usual proportionally. In fact, at this period, or during the rise of temperature in summer, a rough map of the configuration of the Sea Area might be sketched out by paying attention to the temperature alone.

Trip XVIII., March 1888.—Observations were made on February 28th and March 1st, in calm weather, with a light north-easterly air; and also on the 6th, 8th, and 10th of March, with equally light south-westerly wind. The Dunoon Basin and Great Plateau were alone studied in any detail, one observation each being also made at Skate Island and Strachur.

The water coming in from the Channel was rather under 43° in temperature, and in crossing the Plateau it sank to 42°, being as cold as had ever been observed in that position. The mass of the Arran and Dunoon Basins, so far as observations went, was warmer, though showing a steady cooling throughout since the previous trip. The Dunoon Basin showed greatest cooling at its seaward end, as if the Channel water were chilling it—a mode of cooling strongly confirmed by the nearly uniform distribution of temperature from surface to bottom and the absence of any marked surface-cooling. At

Knock the temperature of 44° was reached at 30 fathoms, the surface being at 43°·2, and at Dog Rock at 15 fathoms, the surface being at 43°. Similar evidence of mass-cooling was brought forward by Trip No. VII. in February 1887, when, despite higher temperatures, the general distribution of warmth in the water was very similar.

Trip XIX., March 1888.—To complete the resemblance between the early Spring of 1888 and that of 1886, the air-temperature for March was even lower with regard to the average than that of February, the mean temperature of the air over the Clyde Sea Area being the same (37°·5) for the two months. This trip lasted from March 17th to 31st, with a break from the 24th to the 26th inclusive, and a good general survey of the whole Area was made. The weather varied greatly, the wind being, on the whole, northerly or easterly, and usually light. On the 19th there was a stiff easterly wind with squalls, on the 21st a strong breeze from N.N.E., on the 23rd a fresh north-easterly breeze, sinking to a calm, and on the 28th a gale from the north-east and east, accompanied by a snowstorm.

In spite of the short interval between this trip and the last, there had been a well-marked and general fall of temperature in the water to the extent of nearly 2° on the average. The deep lochs alone retained water exceeding 43° in temperature, the water in the Channel was just at 43°, in the Arran Basin it scarcely exceeded 42° on the average, and was almost homothermic. Everywhere the conditions of the Spring minimum were being closely approximated to, but the temperature was still evidently falling. The whole Dunoon Basin ranged from 42° to 43°. In Loch Goil there was an intermediate maximum rather over 43°·5, and in Loch Fyne the maximum temperature of the Area, 44°·1, occurred on the bottom. The Gareloch was in every way the coldest division, averaging barely 42°.

Trip XX., April 1888.—Observations were made on April 3rd, 6th to 10th, and 14th, either in dead calm weather or with light breezes from a northerly quarter, except on the last day, when there was a light southerly air. The air-temperature for April was still below the average for the season.

The water-temperature, so far as the few observations which were made can show, appeared to be rising after the minimum which must have occurred between this trip and the previous one. In the Dunoon Basin the average temperature of each vertical sounding was about 42°·5, and in the Arran Basin probably about 42°·3, while in every case the surface was warmer, ranging between 43° and 44°. It is unfortunate that more complete observations were not made at this date, as it seems to have been the nearest approach to a return to the conditions found in April 1886, when the systematic work on the Clyde Sea Area was commenced. On that occasion only there was no indication whatever of any physical difference due to configuration. On the present trip the single sounding in Loch Fyne off Strachur showed the minimum temperature of 43°·0 on the bottom, while at similar depths in the Arran and Dunoon Basins the temperature was 42°, or a little less.

This trip is interesting, because the observations are sufficient to enable a comparison

to be made with the state of matters in the northern lochs of the West Coast visited by Dr MURRAY in the "Medusa" from April 20th to May 23rd. On April 20th a sounding off Jura in 103 fathoms gave an average temperature of 43°·3, and on the 21st, somewhat farther north, in a slightly deeper place, the average vertical temperature was 43°·6. Off Kerrara, on the 23rd, the water, 57 fathoms deep, was perfectly homothermic at 43°·5, and on the 22nd, in the Firth of Lorne (114 fathoms), there was a homothermic temperature of 45°; but on May 9th the constant temperature was 44°·2. These observations were made in places fully open to the sweep of Atlantic currents, and it is curious to notice that the water was warmer in the more northerly positions. The mass of Loch Linnhe, Loch Aber, and Loch Sunart had a uniform temperature of about 44°·5 ; and Loch Etive, which was very carefully studied on two separate occasions during the trip, showed still higher temperatures ; maximum readings of 49°·0 were found at 26 fathoms in the deepest part, and a minimum of 44°·6 on the bottom. Nowhere were readings found approximating to the conditions of the Clyde Sea Area, and the suggestion arises that the broad shallow plateau across the entrance to the Area must, about the period of the annual minimum, exercise an independent chilling influence on the inflowing water passing over it.

Trip XXI., June 1888.—From the 2nd to the 11th of June observations were made on six days, most of the time being spent in a very detailed examination of the Gareloch and Loch Strivan, although Loch Fyne and part of the Arran Basin were also visited. May had been a month of normal air-temperature, but June was rather below the average in that respect. The wind was light as a rule, but on the 5th it blew freshly from the south-east; on the 7th, when the Gareloch was under investigation, it was easterly, and sometimes very strong, blowing transversely to the loch. On the 9th, when Loch Strivan was similarly examined, the wind varied from west to north-west, and rose at times to a fresh breeze, blowing, on the whole, down the loch.

Dr MURRAY dealt fully with the observations in his article in the *Scottish Geographical Magazine* already cited. They showed, taken generally, that rapid warming was in progress, the Arran Basin having warmed up to an average vertical temperature of 44°·5. This June was much colder than that of 1887, although warmer, so far as regards the deeper water in particular, than that of 1886. It is interesting to notice that there is no trace of the intermediate minimum in Loch Fyne which was so prominent and puzzling a feature of 1886.

Trip XXII., August–September 1888.—Observations were made on twelve days between August 14th and September 8th. The summer had been the coldest of the three during which observations were made, the air-temperature being as much below the average for the three months June, July, and August as it had been above the average for the same months in 1887. During the observations the weather was, as a rule, warm and calm, strong wind being experienced on only two occasions, August 27th and September 6th, both times a stiff breeze from the south-west. Surface temperature was highest in the lochs, reaching 60°·0 in Loch Fyne, and lowest in the East Arran Basin, where it was 55°·0. The average temperature of the vertical sections was, as might be

expected, highest in the open basins and lowest in the enclosed lochs. No observations were made on the Great Plateau or in the Channel. The arrangement of temperature in all the parts examined was similar to that of the two previous Augusts.

Trip XXIII., October 1888.—Observations were taken in the landward part of the Area, from October 16th to 25th, in calm weather, and these admit of comparison with observations made on the West Coast of Scotland, further north, on the 5th and 6th. August and September had been slightly below the average with regard to air-temperature, but October was a normal month.

The water-temperatures observed showed that surface-cooling had set in. This did not always show itself by the surface layer being colder than that immediately below, but rather by the formation of a homothermic body of water at about 50°, 15 fathoms or more in thickness, beneath which there was a steady fall of temperature to 44°·2 in Loch Fyne, 45°·0 in Loch Goil, and 48°·6 in the deepest part of the Arran Basin. The Dunoon Basin, Loch Strivan, and the Gareloch were entirely occupied by the warm surface stratum, which reached the depth of over 50 fathoms in some places.

A sounding of 73 fathoms in the Sound of Jura on October 1st, and another of 45 fathoms in the Firth of Lorne on the 9th, showed that 53°·5 was the uniform temperature from surface to bottom of the margin of the ocean. In Loch Aber a temperature of 53° prevailed to the bottom, and Loch Etive was also much warmer than the lochs of the Clyde Sea Area.

General Results of the Trips.—It was by an accident of a very remarkable kind that the thermal condition of the water on Trip I. should be so uniform, both in superficial, and vertical distribution as to arouse no suspicion whatever of the true determining causes of temperature change. On every other occasion during the three and a half years covered by the observations, the importance of the physical configuration of the Area was strongly, or at least clearly, marked. Broad distinctions were indicated between the different natural divisions of the Area which, while originally marked off with regard to configuration alone, were found to have a distinct thermal individuality. Arranged according to increasing restriction in communication with the ocean, these divisions are the Channel, Great Plateau, Arran Basin, Dunoon Basin, Loch Strivan, the mountain lochs (Loch Fyne and Loch Goil). The Gareloch occupied a place by itself, or rather along with the Estuary, as showing the influence of the land in an exaggerated manner. Speaking generally, the more completely isolated each natural division was, the more slowly were thermal changes carried on as the seasons succeeded each other, and the lower was the mean annual temperature.

Thermal Conditions of the Divisions of the Clyde Sea Area.

The remainder of this memoir is occupied with a discussion of the conditions of each of the natural divisions carried as far as seemed reasonable in each case, and finally by a general statistical summary of the whole work.

The observations made in the Estuary were too few and scattered to be worth separate consideration, while those in Campbeltown Loch, the Holy Loch, Loch Long, Loch Ridun, and the Kyles of Bute are also not considered, partly because the positions were not characteristic, and the same order of phenomena was better illustrated by one of the other divisions which was fully treated.

The North Channel.

In some respects the Channel is the most important of the physical regions studied, and of all parts of the Area it is the one where observations should have been made most frequently. On account of the small size of the "Medusa," and the rough state of the water caused by tidal races and ocean swell, it was only on a comparatively small number of occasions that full observations could be secured. An effort was made as a rule to obtain soundings off the Mull of Cantyre, where the Atlantic water is quite unaffected by the shore. When this was impracticable, it was often possible to observe off Deas Point, about $1\frac{1}{2}$ mile from land, but when, as was usually the case in winter, it was unsafe to pass through Sanda Sound in the "Medusa," observations had to be made at a point about 5 or 6 miles south of Sanda. Here the water was over 50 fathoms in depth and fairly beyond the Great Plateau. In the summary of observations given in the table, these three stations are indicated respectively by the initials C., D., and S.

Table V.—*Temperature Observations in the Channel.*

No., . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Date, . .	16.4.86	16.4.86	19.6.86	12.8.86	22.9.86	25.12.86	30.3.87	4.5.87	5.5.87	17.6.87	18.8.87	21.9.87	8.12.87	31.12.87	16.2.88	17.3.88	21.3.88	31.3.88
No.of Pts.	9	9	10	13	10	6	6	9	7	12	6	6	9	6	9	6	9	6
Temp., .	42·0	42·0	47·4	52·4	54·5	48·5	44·3	45·8	45·7	48·8	55·3	55·9	49·9	47·3	44·8	43·0	43·0	42·9
Slope, .	+0·0	+0·6	+0·4	+0·2	0·0	−0·2	+0·3	+0·1	+0·7	+2·3	+0·0	−0·1	−0·1	−0·1	−0·4	−0·1	−0·4	0·0
Depth, .	44	68	34	50	65	43	49	60	44	57	48	45	49	48	64	48	62	34
Place, .	S	C	D	D	C	S	S	C	S	S	C	S	S	S	C	D	S	C

The number of observations for each sounding is mentioned in the above table as "No. of Pts." Temp. signifies the mean temperature of the vertical section in degrees Fahrenheit. "Slope" is the range of temperature between the surface and bottom layer of 5 fathoms thick. When the surface is warmer, the slope is positive; when the surface is colder, negative. Depth is given in fathoms.

The striking physical feature of the Channel is the tumultuous rush of the tides (see Part I. p. 653). This appears, from the discussion both of salinity and of temperature, to effect a thorough mixing of the water from bottom to surface; a condition particularly well brought out by the curves of vertical distribution of temperature, which are practically homothermic at all seasons of the year. Of the eighteen soundings in water

for the most part over 50 fathoms in depth, the difference in the mean temperature of the surface and bottom layers of 5 fathoms each exceeded half a degree on three occasions only, and was less than quarter of a degree on eleven occasions. Four times no difference in temperature with depth could be detected.

Fig. 4, Plate XXIII., reproduces several of the vertical temperature curves, all of which show a practically homothermic condition. In No. 2 the dotted part represents the surface temperature found off the Mull of Cantyre at $12^h.10$; below 3 fathoms the curve coincides exactly with that found south of Sanda at $10^h.50$, showing that a perfectly homothermic body of water filled the whole extent of the Channel. The tide had turned and was beginning to run westward when the "Medusa" was off the Mull of Cantyre, and on the return journey the tidal stream was so strong that the vessel was scarcely able, going 6 knots, to make head against it. Surface temperature observations were taken every few minutes, and the results were curiously irregular. Patches of water at 45°·0 were once or twice passed through, but the prevailing temperatures ranged from 42°·0 (the minimum) to 42°·3. Great patches of oilily-smooth water were interspersed amongst the generally rippled surface, and on the whole these seemed to be a fraction of a degree cooler than the rippled surface. The smooth patches suggested the idea of upwelling water from beneath, possibly of greater density and different surface-tension from the rest, forming calms in the same manner as a film of oil does. The late Professor James Thomson suggested, in referring to this observation, that the accumulation of floating objects along the lines of junction of masses of water moving vertically in opposite directions, on account of tidal disturbance, would act as floating breakwaters or dampers for the small ripple undulations.* On the same afternoon the temperature between Sanda and Pladda, on the Great Plateau, was found by two different soundings to be 45°·3 on the surface, 43° at 5 fathoms, and 41°·4 at the bottom in 25 fathoms, the low temperatures being obviously due to overflow from the Arran Basin within, in which the whole mass below 15 fathoms was colder than 42°. Whether the isolated warm surface patches in the Channel were due to direct heating by the very strong sunshine or to isolated flakes of surface water from the Plateau, or the narrow beach of Cantyre, whirling seaward, does not appear. It is quite certain, however, that there was nothing of the nature of a continuous warm upper layer. Whether heating or cooling, the water of the Channel changed its temperature homothermically, and the straightness and parallelism of the vertical curves at all seasons, points unmistakably to continual agitation and thorough mixture by the tidal currents.

The one exception is observation No. 10, on 17th June 1887, when the superficial 5-fathom layer averaged 2°·3 warmer than the bottom layer of 5 fathoms, the whole curve having a distinct positive slope. On that occasion the very hot weather appears to have produced a strong effect on the upper layers. This observation was made south of Sanda, the anticyclonic haze making it impossible to reach the more open water. But even in this case the surface water was more than five degrees colder than the surface

* Miller, "*The Clyde from Source to Sea*," p. 293.

water of the Plateau and neighbouring parts of the Arran Basin, showing that by no means inconsiderable mixing had taken place. In the deep water outside the Plateau there appears to be little variation in temperature in different places. On September 22nd, 1886, from Mr MATHESON's yacht "Oimara," the temperature off the Mull of Cantyre was found to be uniformly 54°·5 in 65 fathoms. Off Corsewall Point, on the eastern edge of the Channel, 30 miles S.E. of the Mull, the mean temperature in 46 fathoms was also 54°·5, the upper 20 fathoms being at 54°·3, the lower layers warming up to 54°·8. On the same occasion, in 70 fathoms off the Maidens on the Irish coast, 20 miles south of the Mull of Cantyre, there was uniform temperature of 55°·1 from surface to bottom. This shows that the Channel type of curve is not confined to the vicinity of the Mull of Cantyre. As soon as the shallow water of the Great Plateau was entered on, the surface temperature fell, the winter condition being in course of formation.

During May and June 1887 several serial temperature soundings were made by the Fishery cruiser "Vigilant,"* in about 40 fathoms, off the southern end of the Outer Hebrides. The curves expressing these showed, as a rule, a uniform positive slope from surface to bottom, the change of temperature being about 1° F. per 10 fathoms. The regularity of these curves is very remarkable, and it is by no means improbable that the Channel curve is derived from this form by thorough mixture of the water. My observations on H.M.S. "Jackal" to the west of Lewis in July and August 1887† suggested a different probable cause, already referred to (*ante*, p. 25). In the Minch I found curves of nearly uniform positive slope similar to those obtained by the "Vigilant" in June (A, fig. 5, Plate XXIII.), but in the open Atlantic, west of Lewis, the typical form was that shown at B (fig. 5), and, as already explained, I think it probable that the upper layer at nearly constant temperature is driven by the surface drift against our coasts, and so enters the Channel. Between the Inner and Outer Hebrides, this water may be supposed to be embayed and brought under the influence of local heating. The curve B is, I believe, the typical form for the upper layers of water in the open ocean, at least near lee shores. It may be viewed as a triply compound curve, uniting the homothermic, inverted, and paraboloid positive types.

Seasonal Change of Temperature in the Channel.—A diagram (Pl. IV. fig. 7) was constructed in order to show the variation of temperature in the Channel with regard to depth and time. This shows the isotherms as almost exactly parallel, straight, vertical lines, crowded together at the times of heating and cooling, spread rather farther apart at the maxima, and widely spaced at the minima. The diagram, being coloured on the principle already mentioned, shows a series of vertical strips of colour, the summer of 1887 showing much deeper tints than that of 1886, but the general order of change is the same for both. A great widening of the isotherms in June, and a corresponding crowding in July and August, 1887, is probably an effect due to incomplete data. Indeed, the diagram is largely hypothetical as regards the spacing of isotherms inter-

* *Eleventh Annual Report of Fishery Board for Scotland for* 1892. Part III.
† *Sixth Annual Report of Fishery Board for* 1887.

mediate between those fixed by observation; but the fixed lines prevent the error from being great at any point. Since the isotherms are vertical, their values show not only the temperatures of surface and bottom water, but the mean temperature of the whole mass of water at all times from April 1886 to May 1888, a period comprising two maxima and three minima. From this diagram of continuous range, checked by constant references to the actual means given in the table, a curve (fig. 6, Plate XXIII.) was drawn, showing the variation of the temperature of the mass of water, the position of each degree being fixed for time by the diagram. The curve, slightly smoothed, may be taken as fairly representative of the actual order and amount of temperature changes.

From a minimum of 42° on April 16th, 1886, the temperature of the water mounted steadily to a maximum of 55° on September 10th, a rise of 13° in 147 days, or at the rate of almost 0°·090 per day. The rate of fall, at first comparatively rapid, fell off after the end of September, but became quicker again after January 20th, and the temperature reached a minimum of 43°·8 (or possibly lower) on February 28th. This was a loss of 11°·2 in 171 days, at the average rate of 0°·065 per day. The temperature continued to rise in the spring of 1887, at first slowly, and then more rapidly, reaching a maximum of 56°·2 on September 5th. Throughout the rise the water was on the average two degrees warmer than at the same period of the previous year. The period from Spring minimum to Autumn maximum was 189 days, and the range of temperature 12°·4, the rate of warming thus averaging only 0°·065 per day, the same as the rate of cooling during the previous winter. The fall of temperature in the winter of 1887 was much more uniform than in 1886. Up till December 10th, 1887 remained warmer, but after that date it became colder than 1886, reaching a minimum of 42°·6 on April 10th, 1888. The interval from Autumn maximum to Spring minimum was on this occasion as much as 217 days, and the total cooling 13°·6, an average loss of 0°·062 per day. In 1886, the period of cooling was 16 per cent., and in 1887, 15 per cent. longer than the period of heating.

The mean temperature of the water for 1886 (interpolating probable values for the first three months) must have been about 48°·2, and the mean temperature of the air at the Mull of Cantyre lighthouse for the same period was 46°·5. The mean water-temperature for 1887 was 49°·3, and the air-temperature 47°·6; the water thus appearing to be on the whole about 1°·7 warmer than the air. This shows that the water of the Channel is on the whole a warming agent during the whole year, and confirms the Gulf Stream drift theory of its origin.

The comparison of air and water temperature in detail brings out several points of interest. The range of air-temperature is greater and its phase earlier than that of water-temperature. Both years showed similar relations. The air curve rose much more steeply than that of the water, which it crossed upward in April close to the water minimum, and came to a maximum in July, from five to six weeks before the water maximum. Descending, the air curve cut the water downward at its maximum, cooled much more rapidly, and came to a double minimum in December and March, the former being the

lower in 1886, the latter in 1887. Taking the date of mean air minimum to be the middle of February, it appears about six weeks earlier than the water minimum. The period of heating for the air is shorter than that for the water in comparison with the period of cooling. In 1886 the period of air-cooling was 24 per cent., and in 1877, 32 per cent. longer than that of heating.

The rate of change of temperature in the mass of the water is also a matter of interest, considered with regard to its fluctuations with time.

TABLE VI.—*Rate of Change of Temperature in the Channel.*

Calculated from Curve.				Calculated from Observations.			
Period.	Days.	Change of Temperature.	Do. per Day.	Periods.	Days.	Change of Temperature.	Do. per Day.
1886.		° F.	° F.	1886.			
April 16–30, .	15	+1·1	+0·074	April 16–June 19, .	64	+5·4	+0·084
May 1–31, . .	31	+2·9	+0·094				
June 1–30, .	30	+2·7	+0·090				
July 1–31, . .	31	+2·6	+0·084				
Aug. 1–31, . .	31	+3·1	+0·100	June 19–Aug. 12, .	53	+5·0	+0·094
Sept. 1–30, .	30	−1·4	−0·047	Aug. 12–Sept. 22, .	41	+2·1	+0·051
Oct. 1–31, . .	31	−2·0	−0·065				
Nov. 1–30, .	30	−1·6	−0·053				
Dec. 1–31, .	31	−1·5	−0·048	Sept. 22–Dec. 25, .	94	−6·0	−0·064
1887.				1886–87.			
Jan. 1–31, . .	31	−2·0	−0·065				
Feb. 1–28, . .	28	−2·2	−0·078				
March 1–31, .	31	+0·6	+0·020	Dec. 25–March 30, .	95	−4·2	−0·044
April 1–30, .	30	+1·1	+0·037	1887.			
May 1–31, . .	31	+1·7	+0·055	March 30–May 4, .	35	+1·5	+0·043
June 1–30, .	30	+3·0	+0·100	May 4–June 17, .	44	+3·0	+0·070
July 1–31, . .	31	+3·7	+0·120				
August 1–31, .	31	+2·5	+0·083	June 17–Aug. 18, .	62	+6·5	+0·105
Sept. 1–30, .	30	−1·1	−0·037	Aug. 18–Sept. 21, .	34	+0·6	+0·018
Oct. 1–31, . .	31	−2·3	−0·074				
Nov. 1–30, .	30	−2·7	−0·090				
Dec. 1–31, . .	31	−2·6	−0·084	Sept. 21–Dec. 8, .	78	−6·0	−0·077
1888.							
Jan. 1–31, . .	31	−2·0	−0·065	Dec. 8–31, .	23	−2·6	−0·113
				1888.			
Feb. 1–28, . .	28	−1·5	−0·054	Dec. 31–Feb. 16, .	47	−2·5	−0·053
March 1–31, .	31	−1·2	−0·037	Feb. 16–March 17, .	29	−1·8	−0·062
April 1–30, .	30	+0·2	+0·007	March 17–21, . .	4	0·0	0·000
				March 21–31, . .	10	−0·1	−0·010

Table VI. gives the mean monthly rate of change calculated from the temperature curve, and also the more irregular deductions for the intervals of time between actual

observations. The latter are used only to check the former. Plotting the rate of change per diem ± with the amount of change as ordinates and time as abscissæ, a curve of great interest is produced. This curve (Plate XXIII., fig. 6) shows that, starting with the spring minimum, the rate of warming is zero, but immediately afterward it increases, at first rapidly, then more gradually, until it reaches a maximum just before the seasonal maximum of temperature. At that moment the rate drops to zero, and cooling commences, at first rapidly increasing, then continuing steadily until the eve of the spring minimum, when the rate of cooling drops off and heating begins. For 1886 the maximum monthly rate of change per day was +0°·104 in August, and −0°·067 in October. In 1887 it was −0°·077 in February, +0°·120 in July, and −0°·090 in November.

Thus, while the temperature was rising rapidly at the time of the maximum of air-temperature, the water was gaining heat throughout at the rate of 1° in 8·3 days in 1887, and 1° in 9·6 days in 1886. When cooling most rapidly in October 1886 it lost 1° in 15 days, and in November 1887 it lost 1° in 11 days. Storing heat thus appears to be a more rapid process than parting with it. In the case of water this is probably due to solar radiation heating it throughout from surface to bottom, whereas in cooling, water radiates heat from the surface only, and the slower processes of convection or even conduction are required to send the heat out of the mass.

The Great Plateau.

The Great Plateau is the threshold of the Clyde Sea Area, and over its sill, which reaches to within 21 fathoms of the surface at low tide, all exchanges of water between the Area and the ocean have to pass. The southern edge of the Plateau is relatively steep toward the Channel, but its surface slopes up very gradually to the narrow belt of minimum depth. So gentle is the slope that in considering temperature changes the whole may be looked on as a uniform level, across which masses of water oscillate with the tides between the deep water to north and south. The middle of the northern edge of the Plateau runs on to the shore of Arran. Its western edge dips westward into the North Channel beyond Sanda, runs up the east coast of Cantyre as far as Davaar Island, and in Kilbrannan Sound dips rapidly to the deep water of the West Arran Basin. On the east side Ailsa Craig rises rather to the south of the highest part of the Plateau, and the slopes are uniform to the coast of Galloway, and northward bordering the East Arran Basin in a wide shallow round the shore of Ayr. The deep water of the East Arran Basin lies toward the west, much nearer the coast of Arran than that of Ayr, and there is a comparatively steep gradient off the island of Pladda at the south end of Arran. The water on the Plateau was, in its average condition, just perceptibly less dense than that of the Channel, and the surface and bottom salinity were practically equal.

Observations were made most frequently on the western part of the Plateau, for in uncertain weather the deep water of the Channel could be reached best to the south of Sanda, and Campbeltown Loch was the only convenient harbour from which to work. Distance from any harbour made the number of observations in the south-eastern part of

the Plateau, about Ailsa Craig, very small. But on the run from Lamlash to Campbeltown, which was frequently made, observations were secured pretty often across the northern end. The common observing places were (1) to the south-east of Pladda, (2) midway between Pladda and Sanda, and (3) to the east or north-east of Sanda. Sometimes no observations could be made beyond the shelter of the land, and then they were usually carried out off Rhuad Point or Davaar Island, near the Cantyre coast, or off Bennan Head, in the south of Arran.

The observations may be grouped for convenience into an eastern and a western set, but the locality of each sounding is in each case indicated. Observations made by the Fishery Board's cruiser "Vigilant," and discussed by Mr HERBERTSON and myself in the Eleventh Annual Report of the Fishery Board for Scotland, furnished some data contemporary with those of the "Medusa," and supplementary to them.

Table VII. gives particulars of dates and mean temperatures at stations on the east and south-east parts of the Plateau.

TABLE VII.—*Observations on the Great Plateau (Eastern Side).*

No.	1	2	3	4	5	6	7	8	9	10	11*	12	13	14*	15*	16*	17*
Date	20.6.86	22.9.86	26.12.86	5.5.87	17.6.87	6.7.87	21.9.87	21.9.87	21.9.87	21.9.87	1.10.87	10.12.87	19.1.88	14.2.88	17.2.88	26.4.88	9.5.88
No. of Points	5	7	4	13	9	13	7	7	4	4	6	6	6	5	5	6	6
Temperature	48·8	54·0	46·3	45·3	49·8	51·5	55·2	55·6	55·3	55·7	53·7	47·7	45·3	44·4	44·3	43·7	44·5
Slope . . .	+5·3	−0·8	−0·1	+1·4 (+2·3 −0·9)	+4·8	+8·9	0·0 (+0·3 −0·3)	0·0	0·1	−0·1	+0·5	0·0	−0·6	−1·4	−1·7	+0·8	+2·1
Place. . . .	P	A	P	A–P	P	P	A–P	A–P	A	A–S	P	P–S	A	P	P–A	A–S	A
Depth . . .	20	26	11	29	25	23	30	28	32	28	22	23	36	30	30	28	25

* "Vigilant" Observations.

P, east or south of Pladda. A, near Ailsa. A–P, between Ailsa and Pladda. A–S, between Ailsa and Sanda.

With so few data, scattered so irregularly over a long interval of time, it would be useless to attempt detailed discussion; but the general average rate of heating and cooling of the mass of water may be deduced as in Table VIII.,—the wide flat expanse of the Plateau allowing one to assume the mean vertical temperature of the station as approximately that of the whole quantity of water in the neighbourhood.

TABLE VIII.—*Rate of Change of Water-Temperature on the Great Plateau (Eastern Side).*

	Period.	Temperature Change.	Days.	Mean rate of Change per Day.	Remarks.
1886	June 20–September 22	+5·2	94	+0·055	
	September 22–December 26 . . .	−7·7	95	−0·081	
1887	December 26–May 5	——	—	——	Valueless through lost minimum.
	May 5–June 17	+4·5	33	+0·136	
	June 17–September 21	+5·6	96	+0·058	
	September 21–October 1	−1·5	10	−0·150	
	October 1–December 10	−4·0	71	−0·056	
1888	December 10–January 19	−2·4	40	−0·060	
	January 19–February 14	−0·9	26	−0·035	
	February 14–April 26	−0·7	71	−0·010	Probably includes minimum.
	April 26–May 9	+0·8	13	+0·061	

Table IX. summarises the observations made on the west and north-west parts of the Plateau.

TABLE IX.—*Temperature Observations on the Great Plateau (Western Side).*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14†	15†	15a	16†	17†
Date	15.4.86	16.4.86	16.4.86	20.6.86	12.8.86	12.8.86	22.9.86	18.11.86	18.11.86	25.12.86	10.2.87	11.2.87	31.3.87	22.4.87	27.4.87	9.5.7	10.5.87	16.5.87
No. of Points	7	9	7	9	14	7	7	6	12	4	6	5	3	8	6	6	9	6
Temperature	42·6	42·2	42·8	48·0	53·0	52·8	54·2	50·3	50·0	46·9	43·8	43·5	43·5	44·5	44·3	45·6	45·4	50·4
Slope	+1·5	+2·2	+2·3	+3·0	+0·7 (+1·3 −0·6)	+0·2	−0·4	+0·2	−0·2	−1·4	−0·1	−0·1	+0·3	+0·9	+1·5	+2·2	+0.7	+1·4
Place‡	S	S–P	R	S–P	S–P	S	S	S–P	D	R	D	R	D	D	D	D	D	D–P
Depth	24	25	20	29	24	28	23	21	20	17	25	19	20	20	29	29	24	22

No.	18†	19*	20	21	22	23	24†	25†	26†	27†	28	29	30	31	32	33	34	35†
Date	26.5.87	18.6.87	6.7.87	6.7.87	17.8.87	21.9.87	5.10.87	6.10.87	6.10.87	1.12.87	10.12.87	22.12.87	31.12.87	31.12.87	17.2.88	6.3.88	10.3.88	1.10.88
No. of Points	6	12	12	12	12	4	6	6	7	6	6	8	3	6	3	3	3	6
Temperature	50·2	50·4	52·0	51·9	56·0	55·0	54·1	54·1	54·1	48·6	47·9	45·3	46·3	44·5	43·7	42·5	42·7	53·4
Slope	+2·0	+4·8	+6·1	+7·6	+2·1	−0·2	+0·6	+0·2	+0·4	−1·2	−0·1	−1·1	−0·7	−0·1	0·0	−0·5	−0·1	−1·5
Place‡	D–P	S–P	S–P	D	S–P	R	D–P	D	D–P	S–P	D–P	D	S	R	D–P	S	R–S	P–S
Depth	24	25	27	23	23	22	26	25	30	26	22	21	20	21	19	20	20	34

D, Davaar. P, Pladda. S, Sanda. R, Rhuad Point.

* Mean of thirteen accordant soundings.

† Observations made by F. C. "Vigilant."

‡ The sign – in this line signifies that the point of observation was between the two stations denoted.

Additional observations were made too near shore to be of equal value with the rest on November 23rd, 1887, in 14 fathoms, when the mean vertical temperature was 49°·6, and on February 1st, 1888, when the mean was 44°·1.

The mean rate of change of temperature as deduced from observations on the western side of the Plateau was so unsatisfactory that it is unnecessary to enter into the details. It is sufficient to point out that differences of several degrees in mean temperature occurred in a distance of 4 or 5 miles, according to the position of the observing stations on the seaward or inner slope of the Plateau, and that such observations must obviously be much affected by local tidal conditions. This state of matters makes it impossible to estimate mean rates of change of temperature over any length of time, although for short periods when the temperature of the whole Area is fairly uniform a comparison might be safely attempted.

The Plateau is so obviously a transitional zone between the oceanic and landward waters that it must be viewed in connection with both, and it can scarcely be treated as a separate natural region.

General Form of Temperature Curve.—The fifty-two temperature curves for the Plateau, summarised in Tables VII. and IX., show an average slope, *i.e.*, range of temperature between the mean for the surface and bottom 5 fathoms, disregarding the sign, of 1°·2. The curves resemble those of the Channel by having less than 0°·3 difference between top and bottom layers in February, March, September, and October, and occasionally in

November and December. Stating this generally, we may say that the water of the Plateau is homothermic only just before the Spring minimum and just after the Autumn maximum. During the months of heating (from April to August) the surface water is usually more than two degrees warmer than the bottom layer, and may be as much as 8 degrees warmer. This is the most heterothermic condition assumed by the water. The great warmth of the surface layers and its sharp contrast with that below may be accounted for mainly from the seaward extension of the hot surface water of the Arran Basin overlying the cooler water of the Channel. From the comparison of curves, it seems that the deeper layers on the seaward side of the Plateau usually correspond in temperature with the mass of water in the Channel. On the inner side, the Channel water of the deep layers of the Plateau is distinctly chilled by contact with the colder deep layers of the Arran Basin.

Curves of negative slope occur from September to April, or during the season of cooling, when the surface water is colder than that beneath. It is interesting to notice that the negative slope on the Plateau was never so great as 2° in 25 fathoms, while the positive slope at times amounted to close on 8°.

Fig. 7, Plate XXIII., shows the typical curves of the four seasons—those of warming, cooling, maximum, and minimum—on the Plateau. It will be noticed that the negative-slope curve of cooling is much less pronounced than the positive-slope curve of heating. It is natural to suppose that this may, to some extent, be due to the fact that all the winter observations were made during the day when cooling by radiation is at a minimum, while the summer observations, also made during the day, were at a time when solar radiation was at a maximum. It will presently be shown, however, that the positive form of the Summer curve is scarcely, if at all, modified during the night. We may assume also that the short and infrequent sunshine of winter does little to check loss of heat by surface radiation. The slighter slope of the negative curve is more probably explained by the fact that the water on the Plateau is practically of uniform salinity throughout, so that when the surface water is cooled its density is increased, and it sinks, rapidly chilling the mass by convection, and so tending to produce a homothermic state. The heated surface water, on the other hand, expands, and its density diminishes by rise of temperature more than it increases by the rise in salinity caused by evaporation. Hence the warm layer lingers on the surface, and the heat passes downward slowly.

It is noteworthy that on the Plateau smooth curves are practically never obtained. At first sight, one would be inclined to attribute at least the minor irregularities to observational error, but experience and repeated experiments have convinced me that this is very rarely the case. A few of the more remarkable contorted Plateau curves are reproduced in fig. 8, Plate XXIII., in order to illustrate the manner in which they vary. Nos. 14 (A), 2 (B), and 5 (C) show increasing degrees of complexity, due to the existence of layers of water superimposed at different temperatures, an effect possibly brought about by the complicated currents of the region, although, as will be shown immediately, instances of

an intermediate maximum or minimum occur for a much longer space of time than can be accounted for on the hypothesis of the tidal currents producing the irregular mixture. In the case of C, the minimum temperature at 13 fathoms is 52°·2, almost the same as that of the homothermic water of the Channel at the same time. The observation was made at a point nearly midway between Pladda and Sanda, but close to Sanda the curve (Table IX. No. 6) appeared homothermic at 52°·8. The sharpness of the included minimum between 9 and 14 fathoms in C leaves some room for the speculation that in the space between 5 and 15 fathoms in No. 6 (D) a similar minimum may have escaped attention. At anyrate, this justifies the great caution adopted in connecting the points of observation to form curves (see p. 9). The last example, Table VII. No. 6, of the Eastern division of the Plateau, fig. 8, E, is too wild in its zigzags to be accepted as natural, and it is only introduced to illustrate the necessity for keeping the vessel exactly in the desired position while all the soundings of a serial set are carried out. On this occasion the first sounding was made about $1\frac{1}{2}$ miles to the south of Pladda, in a depth of 26 fathoms, and temperatures taken at 24, 14, and 4 fathoms. The second sounding gave observations at 18, 8, and 3 fathoms, and the other points were then filled in. At the end, the extraordinary sequence of temperatures induced me to take another bottom temperature, when it appeared that the depth was only 18 fathoms, and the temperature at 17 fathoms 56°·2, and that the "Medusa" had been drifting toward the land while the observation was being made, and so coming into the much warmer shore water. The sea was rough, and the weather dull and rainy, so that landmarks could not be distinguished. The total drift was probably not more than quarter of a mile.

Hourly Observations on Plateau.—On June 17th, 1887, a series of thirteen hourly observations was made when anchored nearly midway between Sanda and Pladda, Davaar bearing N.W. by N. $\frac{3}{4}$ N. distant $6\frac{1}{2}$ nautical miles. Observations were commenced at 20^h0, and carried on until eight on the morning of the 18th. The depth varied from 26 to 27 fathoms, but the deepest water did not correspond with the theoretical hour of full tide, which was 21^h30, low water occurring at 3^h0. The temperature of the air was 60° at the time of commencing observations, 59° at midnight, and 58° at 2 o'clock in the morning. The thermometer for air-temperature was broken during the observations, but the air was not perceptibly colder after two o'clock. The night was dead calm, with a thick haze shutting out the stars and lighthouses, and thus tending to minimise the cooling due to radiation.

The changes which occurred in the twelve hours were of a remarkable character. Fig. 9, Plate XXIV., shows the variation of temperature as ascertained hourly at the surface, 5 fathoms, 10 fathoms, 15 fathoms, and the bottom. The variation of the mean temperature of the whole slice of water is also shown, and the tidal phase is indicated below the figure. The surface temperature fell gradually but irregularly from 59°0 at 20^h0 to 57°·3 at 8^h0. A minimum occurred at 23^h0, another very slight one at 3^h0 (57°·4), and a much deeper minimum (56°·0) at 7 o'clock on the 18th. At 5 fathoms

there was a gentle rise from 51°·4 at 20^{h}0 to 52°·5 at 1^{h}0 during ebb tide, and then a gentle but fairly uniform fall with the rising tide to 51°·4 at 8^{h}0. At 10 fathoms the changes were more pronounced than elsewhere. Starting at 49°·2 the water grew warmer somewhat irregularly until 2^{h}0, when it was 51°·2. The next sounding, at 3^{h}0, when it was low tide, was 48°·2, a drop of 3°, and the subsequent observations showed only a slight warming up to 48°·4 At 15 fathoms the temperature fell from 49°·5 at 20^{h}0 to 48°·2 at 23^{h}0; then rose to 49°·2 at 4^{h}0, and remained constant at that temperature for the rest of the time. The bottom temperature was steady throughout at 49°·2, the greatest variation being one-tenth of a degree.

The average temperature of the whole section was 50°·4 at 20^{h}0, gradually rose to 50°·7 at 3^{h}0, and fell rather more rapidly to 49°·9 at 6^{h}0, showing a tendency to increase again later. The sudden dive of the 10-fathom curve happened while the mean curve was stationary, thus showing that the cooling at 10 fathoms was not due to the intrusion of a mass of cold water. (The actual observations were made a few minutes after each hour).

The interpretation of the mean curve evidently is that as the tide was ebbing the warmer surface water of the Arran Basin was tending to deepen on the Plateau, thus slightly raising the temperature as a whole, but on the flood tide setting in the cooler water of the Channel began to mix with the Plateau water. An attentive study of the vertical curves (fig. 10, Plate XXIV.), explains how the singular fall of temperature at 10 fathoms occurred while the water as a whole remained unchanged in temperature. The mean value of the curves is given in No. 19, Table IX., where the mean slope is seen to be + 4°·8, the mean temperature of the surface 5 fathoms being 54°·0 (extremes 55°·3 and 52°·9), while the mean of the bottom 5 fathoms was 49°·2 (extremes 49°·3 and 49°·1). The first two soundings showed curves of a very simple type (A in fig. 10), where the temperature fell in a paraboloid curve to 15 fathoms, and below that became apparently homothermic. This simplicity entirely misled us, and, in spite of former experience, it was, unfortunately, not thought necessary to fix more points in the lower 10 fathoms. In all the subsequent soundings, however, this was done, and a remarkable distribution came into sight. The minimum was not at the bottom at all, but in a sharp elbow of the sickle-shaped curve, which at 23^{h}0 was found at 15 fathoms, with the value 48°·2 (B in fig. 10). This very abrupt inversion was a constant feature of the curve, and on each successive sounding, the point at which it occurred was found to be higher up, and the inflexion became more pronounced. It reached 10 fathoms at 3^{h}0, and so produced the sudden fall of temperature at that depth (C in fig. 10). There existed, in fact, a thin layer of cold water between the warm heterothermic upper mass of water and the cool homothermic lower layer.

To show more clearly the changes in the distribution of temperature during the period, a time-depth diagram was constructed. This is shown in Plate II. fig. 2. In interpreting such a diagram it is necessary to remember that, when hours only are considered, water in any considerable masses cools or heats so slowly that little rearrangement of the isotherms results from this cause. The isothermal sheets, traversing a heterothermic

mass of water, may thus be considered, if they be sufficiently numerous and the time sufficiently short, as limiting strata of water; and any marked rearrangement of the isotherms must be looked upon as due to the effect of the mixture of contiguous strata, or the intrusion or withdrawal of some of them. In a time-depth section the heating of water from above by absorption of heat or affusion of warmer water on the surface is shown by the isotherms striking deeper. Cooling from the surface by radiation or by the withdrawal of warm upper layers, and the welling up of colder water from beneath, is indicated by a rise of isotherms toward the surface. The spreading out of isotherms apart from each other indicates a mixture of contiguous layers: the crowding together of isotherms may be due to the introduction above or below of water, differing greatly in temperature, or to a shearing motion squeezing the layers between successive isothermal sheets into less space vertically.

In the diagram of Plateau observations it will be seen that until 1 o'clock in the morning all the isotherms had a downward trend, showing that heating was occurring from above. Now, no heat was reaching the water from the sun, which set within half an hour of commencing the observations. Nor was there a warm wind blowing, nor was the temperature of the air much above that of the surface water. Moreover, the maximum surface temperature occurred at midnight. It is perfectly obvious, then, that the heating must be due to warm surface water flowing to the position of observation, and the ebb-tide carrying a strong current of warm surface water from the Arran Basin explains the effect fully. This surface water was accumulating on the Plateau, and displacing the homothermic layer of water derived from the Channel. The thin slice of water colder than 48°·5 served as a complete proof of the truth of this theory. At the time of observation (or, at least, a few hours previously), the mass of water in the Channel south of Sanda showed a minimum temperature of 48°·2 at 20 fathoms, and a temperature of 48°·7 on the bottom. Former experience indicates that the water further west, toward the Mull of Cantyre, would be homothermic and warmer; probably—as indicated in the curve for mean temperature of the Channel—a little over 49°. This warmer water would possibly pass through Sanda Sound, and so cover the western part of the Plateau. But it is evident that a cold layer scarcely above 48° separated the warmer bottom water from the relatively hot surface layers, and this is accounted for by the overflow from the West Arran Basin, which, although very warm on the surface, was colder than 48° at the level of the edge of the Plateau. The isotherm of 52° reached its greatest depth (5 fathoms) at 3^h0, the lower isotherms at 2^h0, but the isotherm of 49° below the cold layer at 1^h0. It was low-water at 3 o'clock, and then the sudden elevation of the cold layer from a mean depth of 15 fathoms to a mean depth of 10 fathoms took place, and the upper isotherms commenced to retreat toward the surface, while the mean temperature of the mass fell steadily, though slightly. The great thickening of the lower homothermic stratum, and the practically unaltered thickness of the cold layer above it, showed that the rising tide was carrying in Channel water beneath, and apparently raising up and causing to flow

back the warm upper layers, the isotherms of which were greatly crowded just above the cold layer.

Additional observations now suggest themselves which might have been made to throw light on many points still left doubtful, but enough has been made out, I think, to show that the flood-tide across the Plateau tends to carry in a mass of Channel water along the bottom, while the ebb-tide rather affects the surface. Probably there is always a current both in flood and ebb sweeping across the Plateau from surface to bottom, but during ebb the surface current seems to do most of the work, and in flood the under current. It is significant of this that the lowest isotherm in the diagram is the first to show an inflection due to the setting in of the flood stream, and the isotherms near the surface are the last.

On the eastern side of the Plateau, as might be expected from its greater distance from the Atlantic, the range between surface and bottom temperature is greater than on the western side, but on the eight occasions when observations were made on the same or on successive days, on both sides of the Plateau, the mean temperature of the vertical soundings never differed more than half a degree.

The Arran Basin.

This is the largest of the divisions of the Clyde Sea Area, and presents a peculiar importance in being the intermediary in all interchange of water between the ocean and the landward divisions. Water from the ocean, thoroughly mixed through all its depth in the Channel, and passed inward across the Great Plateau, finds in the Arran Basin a great reservoir in which it is mixed with landward water from rivers, estuary, and lochs, and from which it passes, carrying the influence of the open sea into the remotest recesses. The large island of Arran serves to divide the basin into three parts, the peculiarities of which are clearly marked. The West Arran Basin is practically Kilbrannan Sound, and in its configuration resembles a sea-loch open at both ends. On the south the opening to the ocean across the Plateau resembles the opening of a sea-loch of the type of Loch Strivan. But the north or upper end sinks into the much deeper trough of the Central Arran Basin, so that the fjord-like character is confined to the steeply sloping parallel sides, and the gradually diminishing width from south to north.

The East Arran Basin, on the contrary, is broad and open on the south, meeting the full breadth of the Plateau between Pladda and Turnberry Point. The trough of water deeper than 50 fathoms runs parallel to the east coast of Arran, and keeps close to the island, while on the east, a wide shallow, an extension northward of the Plateau, sweeps round the shore of the mainland. The relatively shallow portion may be said to occupy nearly two-thirds of the area of the eastern branch. The short north-eastern branch running between Bute and the Cumbraes contains a deep narrow basin barred off from the main trough, but of special interest, because in it the most

complete series of regularly-spaced observations of temperature has been taken. Through this and the narrow, shallow Largs Channel on the east of the Cumbraes, the Arran Basin communicates with the Dunoon Basin.

The Central Branch runs from the north of Arran, throwing off a shallow branch into the Kyles of Bute, practically due north to Otter Ferry, where it communicates directly with Loch Fyne. It is the deepest part of the Arran Basin, and the bottom is very irregular. At the head it shoals up rapidly, stopping in the very shallow Loch Gilp, and Loch Fyne joins it across a sharply defined bar of no great depth.

Although the three main branches of the Basin have individual peculiarities which subject the water contained in them to special conditions, the Arran Basin is essentially one. The orographical map (Plate 2 part I.) shows that the water over 50 fathoms in depth in the three branches is continuous, the main trough running almost S.S.E. from off Kilfinan to off Largybeg, and about the middle, off Inchmarnoch, sending a branch down Kilbrannan Sound as far as Carradale. The main trough of over 80 fathoms runs straight across the mouth of Kilbrannan Sound, from off Tarbert to off Corrie.

The relatively small number of stations at which observations were made in this great division makes it necessary to treat it somewhat generally. Accordingly, the record of each station will first be considered briefly, and then the conditions of the deep part of the Basin will be discussed as a whole.

Only a few irregular observations were made in the southern part of the West Arran Basin, and the results of them are referred to when describing the general temperature sections.

Observations off Carradale. — The deepest part of Kilbrannan Sound, between Imachar and Carradale, is extremely irregular in its configuration, and the station was not always exactly the same. Water of depths sometimes exceeding 80 fathoms occurs close to shallows of 20 fathoms or less. The observations are all, however, characteristic of the deepest part of the West Arran Basin.

[TABLE

TABLE X.—*Temperature Observations off Carradale.*

No. . .	1	2	3	4	5	6	7	8	9	10	11†	12
Date . .	20.9.78	25.8.85	19.6.86	13.8.86	26.9.86	18.11.86	24.12.86	11.2.87	30.3.87	9.5.87	12.5.87	18.6.87
No. of Pts.	13	7	9	13	10	12	9	6	9	6	10	15
Temp. . .	52·9	50·8	45·1	48·5	50·9	51·0	47·5	43·6	43·8	44·9	45·2	47·8
Slope . .	+4·1	+5·8	+5·0	+6·2	+4·4	−2·0	−1·0	−0·9	0·0	+2·5	+1·6	+6·9
H.D. . .	0	30	40	20	30	25	50	60	75	45	...	25
h.t. . . .	...	49·3	44·0	47·0	49·2	51·5	47·7	43·7	43·8	44·2	...	46·2

No. . .	13	14	15	16†	17	18	19	20	21	22	23
Date . .	7.7.87	17.8.87	22.9.87	3.11.87	5.12.87	9.12.87	23.12.87	28.12.87	30.1.88	15.2.88	22.3.88
No. of Pts.	12	12	9	13	16	15	9	15	9	12	12
Temp. . .	48·7	51·0	52·7	51·2	48·8	47·9	46·0	45·9	44·8	44·4	42·5
Slope . .	+8·1	+8·4	+3·8	−2·1	−0·2	−0·3	−1·3	−1·8	−0·2	−0·8	−1·0
H.D. . .	40	40	30	30	80	80	...	60	80	40*	35
h.t. . . .	47·1	48·9	51·6	52·1	48·8	47·9	...	46·1	44·8	44·2	42·8

Assume 80 fathoms as depth.

* Here the homothermic 40 fathoms were the upper half. † Observations made by F.C. "Vigilant."

In Table X. two data are tabulated which acquire much importance in the Arran Basin. These are the homothermic depth (H.D.), *i.e.* the depth of the mass of water in which the whole range of temperature is less than 0°·5. This is almost always the lower part of the water, and in order to arrive at comparable results the depth is assumed as 80 fathoms in all cases (although occasionally the sounding may have been in slightly shallower, and sometimes in slightly deeper, water), and the homothermic depth is arrived at by subtracting from 80 the depth in fathoms at which the homothermic part begins. The second datum, *h.t.*, is the mean temperature of the homothermic layer. Incidentally, this is, of course, the mean temperature of the lowest five fathoms, so that by adding (algebraically) the slope, the mean temperature of the upper five fathoms is at once obtained.

Observations 1 and 2 of Table X. were made by Mr J. Y. BUCHANAN, F.R.S., in 1878 and 1885 respectively; Nos. 11 and 16 were done on the Fishery cruiser "Vigilant" in 1887; the remainder were all done on the "Medusa."

The curves were practically homothermic in the cold months, December to March. During the period of heating, May to August, the positive slope of the curves greatly increased, the homothermic layer shrunk until it occupied the lower third only, and the form of the curve was practically a paraboloid, although occasionally very irregular in outline. The upper part of the curve then assumed a negative slope, and the water rapidly became homothermic as the minimum approached.

It is an interesting fact that the homothermic mass of water covering the bottom changed its temperature as rapidly as did the whole quantity of water, surface included, and often more rapidly. There is no trace of these heat transactions taking place through the upper layers, and the evidence points clearly to an equalisation of temperature beneath by under currents, while the upper layers, if mixed at all, were so much influenced by radiation or surface drainage from the land that equilibrium was rarely established.

As all the stations of the Arran Basin showed the same order of phenomena, the complete discussion of Garroch Head and Skate Island, where the observations were most numerous, will suffice to illustrate the seasonal changes for the whole.

Observations off Loch Ranza.—Observations were made at the head of Kilbrannan Sound, about midway between the Island of Arran and Skipness Point, with Loch Ranza open. This was in the deep channel of the West Arran Basin, before it united with the West and Central Arran Basin off Inchmarnoch.

TABLE XI.—*Temperature Observations off Loch Ranza.*

No.	1	2	3	4	5	6	7	8	9
Date	9.2.87	30.3.87	9.5.87	18.6.87	7.7.87	22.9.87	5.12.87	2.1.88	15.2.88
No. of Points	6	6	6	6	9	6	12	9	9
Temp.	44·0	43·8	46·0	50·1	48·6	53·1	48·3	45·9	44·5
Slope	−0·6	−0·2	+2·3	+6·4	+8·5	+3·6	−0·3	−1·4	−0·9
H.D.*	45	...	...	...	10	0	...	35	30
h.t.	44·0	...	...	...	46·3	...	...	46·2	44·7

* Only mentioned when sounding is 50 fathoms or over, and taken with reference to depth of 55 fathoms.

The observations at this station were less satisfactory than at most of the others. In the main they corresponded closely with those at Carradale.

Observations off Largybeg.—Observations were made in the deep trough lying about two miles east of Arran, with Largybeg Point abeam. This is near the southern end of the great depression of the East Arran Basin, where it begins to shoal toward the Plateau.

TABLE XII.—*Temperature Observations off Largybeg.*

No.	1	2	3	4	5	6	7	8†	9†	10	11†	12	13	14	15†	16
Date	9.7.84	12.8.86	9.2.87	5.5.87	17.6.87	12.8.87	20.9.87	5.10.87	10.10.87	10.12.87	13.1.88	17.2.88	30.3.88	8.4.88	19.10.88	18.12.88
No. of Points	4	13	6	9	15	11	7	11	10	9	14	9	6	9	8	8
Temp.	50·0	49·6	43·4	44·8	47·8	52·8	53·3	53·9	54·2	48·0	45·6	43·5	41·9	42·3	51·7	46·5
Slope	+9·6	+7·7	−0·3	+4·4	+6·1	+7·6	+2·5	+0·6	+2·5	−0·2	−1·3	−1·5	−0·5	+0·7	−0·4	−1·9
H.D.	20	0	...	...	30	0	...	30	30	60	30‡	30*	60	50	30	0
h.t.	47·9	...	...	...	46·1	...	...	53·5	53·1	48·0	45·8	43·0	41·9	42·1	51·9	...

Depths assumed, 60 fathoms. Depths over 45 alone considered.

* The Upper 30 Fathoms homothermic. † Observations by "Vigilant." ‡ Compare with 12.1.88 when=60 and 45·3.

The curves are roughly similar to those of Carradale, so much so that in February 1888 both stations showed the upper 30 fathoms of water in a homothermic condition. Frequently in summer the mean temperature at Largybeg, and also the positive slope, were somewhat greater than at Carradale. The curves, too, showed more variety. In August the whole mass of water became heterothermic, with a strong positive slope. On both occasions (Nos. 2 and 6) these curves approximated more to the North Atlantic type than any others observed in the Sea Area. They are reproduced as A and B in fig. 11, Plate XXIV. An approach to a sickle-shaped curve, C, is also shown. The peculiarities of these curves may be due to the great surface of shallow water to the eastward, which in summer acquires a high temperature.

Observations off Brodick.—The position in which observations were made at this station should have been the greatest depth of the West Arran Basin, lying about 5½ miles east of the coast of Arran, with Brodick Bay open ; but on account of the frequent roughness of the sea and the absence of convenient landmarks, the exact position was not always found.

TABLE XIII.—*Temperature Observations off Brodick.*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14†	15	16	17	18	19†
Date	13.6.79	15.4.86	17.4.86	20.6.86	23.9.86	19.11.86	26.12.86	9.2.87	3.4.87	5.5.87	17.6.87	12.8.87	20.9.87	27.10.87	10.12.87	17.2.88	30.3.88	19.8.88	19.12.88
No. of Pts.	10	6	8	5	4	9	9	6	10	13	18	15	9	13	12	12	9	6	8
Temp.	43·9	41·6	41·5	45·4	52·4	50·8	47·4	43·7	43·6	44·6	47·7	50·1	52·0	52·5	47·6	44·4	42·0	50·6	46·8
Slope	+9·4	+1·2	+1·4	+6·7	+4·5	−1·3	−2·2	−0·8	+0·6	+3·3	+6·4	+8·9	+5·6	−0·9	−2·1	−1·9	−0·5	+7·5	−1·4
H.D.	55	70	65	45	0	50	35	45	30	50	50	10	0	40	45*	40	30	10	35
h.t.	42·7	41·5	41·4	44·1	...	51·2	48·0	44·2	42·8	44·3	46·3	47·1	...	52·9	47·6	44·8	42·4	47·1	47·4

Assume depth as 75 fathoms.

* Below the homothermic layer comes 15 fathoms of rapid slope.

† Observations by F.C. "Vigilant."

The curves on the whole closely resembled those observed at the same date at the Largybeg station. As in the former instance, there were several curves closely approaching the oceanic type, and in particular two remarkable specimens of inverted positive curves were presented in September 1886 and September 1887, Nos. 5 and 13 in Table XIII. These were the only cases in which there was no homothermic water present, but the variation in the depth of the homothermic water at other seasons was somewhat irregular.

Cross-sections in East Arran Basin.—In August 1886 and September 1887 a number of observations were made in order to test the influence of the shallow shore waters on the general temperature of the whole about the time of the annual maximum.

On August 27th, 1886, observations were made at several points between Whiting Bay, in Arran, and Ayr, a distance of 17½ miles. The surface temperature on the Arran coast was 55°·3, in mid-channel 55°·4, and on the Ayrshire coast 57°·5. On a section drawn to

represent the distribution of temperature in depth, the isotherms ran nearly straight from the Arran coast across the deep water until the depth diminished to 25 fathoms on the coast of Ayr; the temperature at 15 fathoms being 53°·0, and at 25 fathoms 51°·0. But at this line, about 3 miles from the shore, the isotherms suddenly dipped, 55° being the bottom temperature when the depth became 15 fathoms. This indicates the accumulation of a belt of warm water along the gently sloping shore to a distance of three miles. The strip of water, from the land down to the depth of 15 fathoms, had an average temperature about 56°, while the average of the surface stratum 15 fathoms thick, across the Basin to the edge of the warm water, was about 54°. The weather during this trip was fine, with a light south wind blowing at right angles to the plane of the section, and a slightly ruffled sea.

On September 20th, 1887, two cross-sections were made in perfectly calm weather, the day being very warm, with slight haze. The first series of observations, from the depression between Garroch Head and Cumbrae Light to Brodick, showed the lower isotherms running horizontally. That of 52° coincided with the depth of 40 fathoms; water below this temperature was confined to the deep part of the East Arran Basin, and did not cross the ridge into the depression of the north-east branch. The isotherm of 53° was horizontal at 30 fathoms until within 2 miles of the Garroch Head sounding, when it dipped suddenly. The isotherms of 54° and 55° were curved. The former was at 30 fathoms off Garroch Head, rose to 15 fathoms in the deepest part of the trough, and sank to 21 fathoms against the Arran coast. The isotherm of 55° rose from 15 fathoms, 2 miles from Garroch Head, to the surface at the deepest sounding, and sank to 18 fathoms against the Arran coast. This showed that the upper layers of the deepest water were on the average, at the same plane, nearly a degree colder than the water along the coast.

A more important section was then made from Brodick Bay to Irvine, a distance of 18½ miles. The section drawn from the observations is given in fig. 12, Plate XXIV. The of surface temperature was practically constant at 56° all the way over, and until the depth 45 fathoms was reached, beyond the deepest trough, the other isotherms ran in the main horizontally, 55° at about 15 fathoms, 54° at about 23, and 53° at about 30 fathoms. But when the depth of 30 fathoms was reached, 2½ miles further, and 4½ miles from the Ayrshire coast, the bottom temperature was over 55°, so that the isotherms must have dipped very abruptly. On this occasion the upper layer of 30 fathoms had an average temperature of about 54°·7 all the way from the Arran coast for 11½ miles, until the depth of 45 fathoms on the Ayrshire coast was reached, where it met a body of shallow water 7 miles wide, averaging 55°·6 in temperature. Here there was a smaller actual difference of temperature between the deep and the shallow water than in August 1886, but a very much larger quantity of water had been affected by the heating power of the shallows.

Since so few observations were taken along the wide shallow coast of Ayr, it is obviously impossible from the data collected to estimate the total heat content of the

Arran Basin at a given time with any approach to accuracy. All we can say definitely, from the two cross-sections available, is that in summer the isothermal sheets are flexed upward in the deepest water, and downward toward the shore, the abruptness of the downward bend being in some inverse proportion to the gradient of the shore. Were it not for the section (fig. 12) being made in a spell of anticyclonic calm, the influence of a west wind might have been credited with producing the isothermal arrangement shown.

From observations I made previously on a wide sand-beach on the Firth of Forth, it appears that in winter the water resting on the beach is chilled, relatively to that beyond shore influence, in much the same proportion as it is heated by contact with the sand in the summer. What is true of a tidal beach probably holds for shallow water generally, and we may conclude that the isothermal sheets will be curved upward by shallow water in calm weather during winter, when the shore waters are colder than those in mid-channel.

In discussing the distribution of temperature in a mass of water, it is important to consider isothermal *sheets*, which are never, except in rare circumstances, horizontal planes. Isothermal lines plotted on a section simply represent sections of the isothermal sheets, the convolutions of which, in some cases, are very complicated. An attempt might be made to construct a model, showing by thin sheets of coloured gelatine the arrangement of water-temperature in three dimensions, but it does not admit of easy diagrammatic representation on paper.

Observations between Garroch Head and Cumbrae Light.—The tongue of deep water branching off from the East Arran Basin between Bute and Little Cumbrae is the main channel through which the seaward water reaches the Dunoon Basin, and through it the eastern lochs and estuary. Being close to Millport, the head-quarters of the "Medusa," it was found possible to make very frequent observations in a depth of 60 fathoms.

The fifty-one observations made in this depression are very interesting, and might be discussed in great detail. As, however, it is more important in some ways to study minutely the effects of heat in the deeper water off Skate Island, I shall here treat only of the main features of the Garroch Head observations.

In form the curves resembled those obtained off Brodick, but the larger number allows one to study the form of the curve in relation to season with some prospect of trustworthy results.

Positive slope was shown in the vertical curve on twenty-two occasions, zero slope once, and negative slope twenty-eight times. The positive slope was always much greater than the negative; thus on fifteen occasions the surface layer of 5 fathoms was more than 2°·3 warmer than the bottom layer of the same depth, while only once was it more than 2°·3 colder. The maximum positive slope was 9°·7, the maximum negative slope 3°·2. This shows in an interesting way how heated water keeps to the surface, while cooled water sinks and equalises the temperature, the salinity at surface and bottom not being very different at this station.

The rate of gain and loss of heat by the mass of water as a whole, and by the upper and lower layers, is given in Table XV., which shows the best results that our work on the Clyde Sea Area produced regarding temperature changes in comparatively short intervals of time. Sounding No. 25 is omitted from consideration, because it was made under different conditions, and possibly not quite in the same place as soundings 24 and 26. The effect of the different behaviour of heated and chilled surface water is brought out by the much greater average rate of cooling than of heating.

TABLE XIV.—*Temperature Observations off Garroch Head.*

No.	1	2	3	4	5	6	7	8	8A	9	9A	10	11	12	13	14	15
Date	29.8.78	21.9.78	24.8.85	17.4.86	21.6.86	6.8.86	13.9.86	29.9.86	29.9.86	13.11.86	15.11.86	2.12.86	11.12.86	16.12.86	27.12.86	1.1.87	10.1.87
No.of Pts.	13	14	7	9	5	13	7	7	7	7	8	9	11	9	12	10	11
Temp.	51·0	52·9	50·2	41·6	45·3	48·9	51·7	53·3	53·2	51·3	51·2	49·8	48·3	47·4	45·8	45·8	45·1
Slope	+9·7	+6·6	+9·0	+1·5	+6·0	+5·9	+5·4	−0·9	−0·7	−1·6	−0·9	−2·1	−1·4	−1·7	−2·3	−1·0	−3·2
H.D.	0	0	0	40	40	25	10	20	25	40	50	0	30	40	30	35	20
h.t.	...	...	...	41·4	44·3	47·5	49·4	53·6	53·5	51·6	51·1	...	48·6	47·6	46·3	46·0	46·0

No.	16	17	18	19	20	21	22	23	24	25†	26	27†	28	29	30	31	32
Date	20.1.87	31.1.87	12.2.87	1.3.87	8.3.87	18.3.87	3.4.87	9.4.87	19.4.87	4.5.87	5.5.87	26.5.87	16.6.87	6.7.87	1.8.87	16.8.87	20.9.87
No.of Pts.	8	2	9	8	8	10	8	9	8	9	10	11	12	12	12	15	9
Temp.	44·1	44·1	43·9	43·7	43·8	43·7	43·6	43·9	44·0	44·4	44·6	45·6	47·9	48·7	51·3	52·2	53·8
Slope	−0·8	−0·2	−1·9	+0·2	−0·5	−0·8	+0·2	−0·2	+1·0	+2·3	+2·4	+2·5	+7·1	+2·9	+8·9	+4·9	+1·8
H.D.	20	60	50	50	55	45	50	60	50	25	40	15	10	50	20	30	20
h.t.	44·0	44·1	44·1	43·7	43·8	43·9	43·5	43·9	43·9	43·1	44·3	44·0	46·4	48·3	48·0	51·0	53·2

No.	33†	34†	35	36	37	38	39	40†	41†	42	43	44	45	46†	47	48	49
Date	25.10.87	31.10.87	10.11.87	2.12.87	15.12.87	19.12.87	8.1.88	13.1.88	16.1.88	11.2.88	17.2.88	30.3.88	10.4.88	11.5.88	16.5.88	29.8.88	29.10.88
No.of Pts.	9	10	11	9	9	15	9	9	8	9	12	9	9	9	12	8	6
Temp.	52·3	52·1	50·6	48·4	46·6	46·2	45·5	45·1	45·4	44·3	44·4	42·1	42·4	43·9	43·9	51·1	51·0
Slope	−1·1	−1·3	−2·1	−0·2	−1·6	−2·1	−0·1	−0·7	−1·4	−0·3	−1·7	−0·4	+1·3	+3·0	+3·3	+5·9	0·0
H.D.	25	50	0	50	20	50	30	55	35	50	10	60	40	35	30	10	60
h.t.	52·6	52·1	...	48·4	47·4	46·4	45·5	45·2	45·7	44·3	44·9	42·1	42·2	43·1	43·2	48·8	51·0

† Observations by F.C. "Vigilant."

TABLE XV.—*Rate of Change of Temperature off Garroch Head.*

Date.	No. of Days.	Section—Whole Depth.		Upper 5 Fathoms.		Bottom 5 Fathoms.	
		Temp. Change.	Temp. Change per Day.	Temp. Change.	Temp. Change per Day.	Temp. Change.	Temp. Change per Day.
17 Ap. 86–21 June	63	+3·7	+0.059	+7·3	+0·116	+2·8	+0·044
21 June–6 Aug. .	46	+3·6	+0·079	+3·0	+0·065	+3·1	+0·067
6 Aug.–13 Sep. .	38	+2·8	+0·074	+1·6	+0·042	+2·1	+0·055
13 Sep.–29 Sep. .	16	+1·6	+0·100	−1·8	−0·110	+3·5	+0·219
29 Sep.–15 Nov.	47	−2·1	−0.045	−2·6	−0·055	−2·6	−0·055
15 Nov.–2 Dec. .	17	−1·4	−0·082	−1·3	−0·079	−0·3	−0·019
2 Dec.–11 Dec. .	9	−1·5	−0.169	−1·7	−0·188	−2·2	−0·244
11 Dec.–16 Dec. .	5	−0·9	−0.180	−1·5	−0·300	−1·2	−0·250
16 Dec.–27 Dec. .	11	−1·6	−0.149	−1·6	−0·149	−1·0	−0·091
27 Dc. 86–1 Ja. 87	5	0·0	0 0	+0·7	+0·140	−0·6	−0·120
1 Jan.–10 Jan. .	9	−0·7	−0·078	−2·2	−0·244	+0·2	+0·022
10 Jan.–20 Jan. .	10	−1·0	−0·100	+0·4	+0·040	−2·0	−0·200
20 Jan.–31 Jan. .	11	0·0	0·0	+0·8	+0·073	+0·2	+0·018
31 Jan.–12 Feb. .	12	−0·2	−0·016	−1·8	−0·150	−0·1	−0·008
12 Feb.–1 Mar. .	17	−0·2	−0·012	+1·7	+0·100	−0·4	−0·023
1 Mar.–8 Mar. .	7	+0·1	+0·014	+0·6	+0·086	+0·1	+0·014
8 Mar.–18 Mar. .	10	−0·1	−0·010	−0·1	−0·010	+0·2	+0·020
18 Mar.–3 Ap. .	16	−0·1	−0·006	+0·7	+0·044	−0·3	−0·018
3 Ap.–9 Ap. . .	6	+0·3	+0·050	−0·1	−0·017	+0·3	+0·050
9 Ap.–19 Ap. . .	10	+0·1	+0·010	+1·2	+0·120	0·0	0·0
19 Ap.–5 May .	16	+0·6	+0·037	+1·6	+0·100	+0·2	+0·012
5 May–26 May .	21	+1·0	+0·048	+0·1	+0·005	0·0	0·0
26 May–16 June	21	+2·3	+0·110	+6·8	+0·324	+2·2	+0·109
16 June–6 July .	20	+0·8	+0·040	+1·4	+0·070	+1·8	+0·090
6 July–1 Aug. .	26	+2·6	+0·100	+4·8	+0·185	−0·2	−0·009
1 Aug.–16 Aug. .	15	+0·9	+0·060	−1·2	−0·080	+2·8	+0·189
16 Aug.–20 Sep. .	35	+1·6	+0·046	−0·9	−0·026	+2·2	+0·063
20 Sep.–25 Oct. .	35	−1·5	−0·043	−3·2	−0·091	−0·3	−0·009
25 Oct.–31 Oct. .	6	−0·2	−0·033	−0·6	−0·100	−0·4	−0·067
31 Oct.–10 Nov. .	10	−1·5	−0·150	−1·7	−0·170	−0·9	−0·090
10 Nov.–2 Dec. .	22	−2·2	−0·100	−1·2	−0·054	−3·1	−0·141
2 Dec.–15 Dec. .	13	−1·8	−0·138	−2·3	−0·176	−0·9	−0·070
15 Dec.–19 Dec. .	4	−0·4	−0·100	−1·5	−0·375	−1·0	−0·250
19 Dc. 87–8 Ja. 88	19	−0·7	−0·037	+1·3	+0·069	−0·7	−0·037
8 Jan.–13 Jan. .	5	−0·4	−0·080	−1·1	−0·220	−0·5	−0·100
13 Jan.–16 Jan. .	3	+0·3	+0·100	−0·2	−0·066	+0·5	+0·166
16 Jan.–11 Feb. .	26	−1·1	−0·042	−0·4	−0·015	−1·3	+0·050
11 Feb.–17 Feb. .	6	+0·1	+0·016	−0·7	−0·117	+0·5	+0·083
17 Feb.–30 Mar. .	41	−2·3	−0·056	−1·3	−0·031	−2·6	−0·053
30 Mar.–10 Ap. .	11	+0·3	+0·026	+1·6	+0·145	−0·1	−0·009
10 Ap.–11 May .	31	+1·5	+0·048	+2·6	+0·084	+0·9	+0·029
11 May–16 May .	5	0·0	0·0	+0·2	+0·040	−0·1	−0·020
16 May–29 Aug.	105	+7·2	+0·068	+8·4	+0·080	+5·8	+0·055
29 Aug.–29 Oct. .	61	−0·1	−0·016	−3·7	−0·060	+2·2	+0·036

The averages taken from Table XV., omitting the cases of no change of temperature, are shown in Table XVI. Roughly speaking, the fall of temperature is one-third more rapid than the rise.

TABLE XVI.—*Average Daily Rate of Heating and Cooling in F.°*

	Whole Mass.		Surface Layer.		Bottom Layer.	
	Heating.	Cooling.	Heating.	Cooling.	Heating.	Cooling.
Average rate, .	+0·057	−0·075	+0·096	−0·120	+0·069	−0·086
Maximum rate, .	+0·110	−0·180	+0·324	−0·375	+0·219	−0·250
Number of cases,	19	22	20	24	20	22

These averages are, of course, not strictly comparable, as they are not the averages of equal periods; but they are quite trustworthy for the comparison of temperature changes at surface and bottom with those of the whole mass. The surface layer heated and cooled one-third more rapidly than the bottom layer, while, on account of intermediate changes, the whole mass of water changed its temperature more slowly than either of its extreme surfaces. The much more rapid progress of cooling than of heating, indicated by the greater positive than negative slope of the vertical curves, and demonstrated by the averages given in Table XVI., is probably entirely due to the aid which downward convection gives to the processes of heat transference by conduction, and mixture by winds or tidal currents.

Homothermic conditions preponderated in the months of falling and minimum temperature, but were restricted to the lower layers, and sometimes lost altogether during the months of rapid heating and maximum temperature. Observations of density at Garroch Head were not made as often as was to be wished. The average of six at wide intervals gave the surface density at 60° as 1·02417 and the bottom 1·02504. This gives for homothermic conditions a range of −0·00087, which for the greatest positive slope (+9°·7) would be increased to −0·00226, and for the greatest negative slope (−3°·2) diminished to −0·00050, which might lead to a reversal of the density gradient very readily. The downward convection, which occurs at intervals during the months of cooling, naturally tends to perpetuate a homothermic state, and so make it characteristic of the season; but even during the period of warming, the heterothermic condition, incidental to the gain of heat by surface exchange, may be overcome in a day or two by the influence of strong wind from a direction which ensures complete mixing of the water.

Some sets of consecutive curves showing the phenomena of temperature changes may be cited as characteristic.

Fig. 13, Plate XXIV., shows very well the transition from a marked positive to a slight

negative slope at the period of maximum. The curve A has mean temperature 51°·7, and its form approaches the oceanic type, already showing equalisation of temperature in the upper layer. Curve B, sixteen days later, shows that the surface layer of 5 fathoms has cooled 1°·8 by radiation upward, and conduction downward, probably the latter predominating. At 22½ fathoms the temperature is the same in both, but below that very great heating has gone on, the rate of increase of temperature increasing with the depth, so that in the bottom 5 fathoms there was a rise of 3°·5—twice as much as the loss at the surface. Curve B has mean temperature 53°·3, the highest temperature observed at this station with a negative slope. Unfortunately, the density of the water was not determined on either occasion. It might be supposed that, as the surface water cooled to a certain temperature between 55° and 53°, its density became greater than that beneath, and mixture resulting in equalisation of temperature immediately ensued. It is unlikely, however, that so decided an increase of density would result, but a decrease of density gradient would greatly facilitate the action of tide and wind in producing mixture. Figure 14, Plate XXIV., is an interesting case of the steady fall of temperature in winter, the curves retaining a distinct negative slope. In A the surface cooling seems to have been prevented from producing its full effect more than half-way down; but in B and C the curves show very regular cooling, the rate increasing towards the bottom. Curve D shows the remarkably superficial effect of very cold weather when the surface water is much fresher than that beneath, and curve E shows how the surface chilling was annulled a few days later, probably by warmer water brought from the seaward part of the Basin by the tide, while cooling went on steadily below. The mean temperature of curves D and E is, however, practically unchanged: the effect might be due to mixture only.

Fig. 15, Plate XXV., illustrates with more detail than fig. 13 the gradual process by which the great slope of the curve of heating diminishes as the maximum temperature approaches, and how the fall of surface temperature goes on while the temperature of the mass as a whole, and of the bottom temperature especially, continues to rise. Although the volume of the water near the surface is much greater than that at greater depths, it is not likely that the cooling of the upper 17 fathoms by 2° can give out heat enough to warm the lower 40 fathoms by nearly 5°, and we must look elsewhere than to the surface for the main source of heat. This in the present case was probably the warm water filling the Dunoon Basin, which appeared to catch and store up the comparatively warm upper layers of the Arran Basin, and by a return underflow affected the Garroch Head depression.

Fig. 16, Plate XXV., serves to show how gradually the homothermic curve resumes a positive slope as surface heating recommences in Spring. The lower 45 fathoms remain practically unchanged, while the surface layer has been warmed up by two degrees, and the slow penetration of the heat downward is shown by the typical paraboloid form of the upper part of the curve.

Combining all the results shown above in figures and curves into a section illustrating

the distribution of temperature in time and depth, the general history of the warmth cycle at the Garroch Head station appears at a glance. The section on Plate III., fig. 3, is interesting when compared with that for the Channel. The isotherms have no longer the simple form and uniform perpendicular direction, but the lagging of the deeper water is a conspicuous feature. The colours indicative of high temperature are widest at the top, but taper to a narrow band at the bottom, where the colours showing cooler water occupy proportionally more space. Just after the maximum and after the minimum temperature of the whole mass of water has been reached, the bands of colour lie vertically as in the Channel section. In the course of heating it appears by the section that the surface reached 50° on 15th June 1886, and remained above that temperature until the 19th November. The isotherm of 50° reached the depth of 30 fathoms on August 27th, and the bottom (65 fathoms) on September 14th; so that the bottom was three months behind the surface in warming to a given extent. But temperature at the bottom only remained above 50° until December 10th, or only 20 days later than the surface. So that in cooling the lag of the season at the bottom was only one quarter as much as in heating. On this occasion the isotherm of 54° reached its deepest point (15 fathoms) on September 14th.

In 1887 the surface was at 50° on May 12th: that isotherm had worked its way down to 30 fathoms by August 4th, and to the bottom by August 17th. By November 14th, or after six months, the surface temperature was again 50°, and the same temperature was reached at 30 fathoms on November 18th, and at the bottom by November 20th. Thus, while the warming at the bottom lagged more than three months behind the surface, the cooling was only six days behind. The rate of warming was interrupted by a comparatively cold spell early in July, but the isotherm of 54° reached 35 fathoms, its deepest point, on September 27th.

The observations for the maximum of 1888 are not complete, but the isotherm of 50° never seemed to reach the bottom at all, and 54° only penetrated to $7\frac{1}{2}$ fathoms.

Comparing 1886 and 1887, we see that the warm period (denoting by this expression the time when the water-temperature was over 50°) lasted at the surface respectively for 5 and 6 months, while the warm period at the bottom lasted respectively for barely 3 and scarcely more than 3 months; in other words, for just half the time.

The slow penetration of heat giving a great inclination to the isotherms, scarcely extended below 35 fathoms, or half way down. In the lower half the temperature changed nearly homothermically; as it did throughout for the greater part of the year.

The difference from the Channel is shown by the reduction of the range of temperature in the lower layers, and its retardation in date. This is evidently due to reduced facility for mixing the deeper and the superficial layers of water. The deeper half of the water —that lying near or below the level of the bar separating the north-eastern branch from the main East Arran Basin—behaves very similarly to the Channel water, heating and cooling on the whole nearly simultaneously throughout its whole extent. The sharp contrast lies between this mass and the surface layers. The greater range of salinity is

associated with this result, it may be either as a cause or an effect. The thermal conditions would indicate that in the upper half of the water at Garroch Head the tidal or wind currents gave rise mainly to horizontal movement in sheets, while in the lower layers the movement, possibly on account of the slopes of the bottom, was more complicated, and had a considerable vertical component.

Observations in Inchmarnoch Water.—This station is the meeting-point of the deep channels of the East and West Arran Basins, from which the greater depths run northward through the Central Arran Basin.

TABLE XVII.—*Temperature Observations in Inchmarnoch Water.*

No.	1	2	3	4	5	6	7	8	9	10	11	12
Date	19·6·86	6·8·86	25·9·86	18·11·86	11·2·87	30·3·87	9·5·87	16·6·87	7·7·87	12·8·87	22·9·87	15·2·88
No. of Pts.	9	16	7	9	9	9	6	15	15	18	10	13
Temp.	44·4	48·2	50·7	50·9	44·1	43·7	44·7	47·2	47·8	49·9	52·1	44·6
Slope	+2·5	+8·4	+5·5	−1·4	−0·5	0·0 (+0·3 −0·3)	+2·4	+6·3	+7·6	+7·9	+6·2	−0·9
H.D.*	60	5	0	55	83	85	55	25	35	0	0	50
h. t.	44·3	45·6	...	51·3	44·1	43·7	44·4	46·5	46·3	...	...	44·8

* Assuming depth = 85 fathoms.

The curves here call for no special comment, being intermediate in character between those of the Brodick and Skate Island stations, and in all their leading peculiarities the description of the Skate Island curves is sufficient.

Observations off Ardlamont Point.—Observations at Ardlamont were taken in the spur of the Central Arran Basin, which runs up into the Kyles of Bute, and they give a good idea of the general temperature of the water entering that channel.

TABLE XVIII.—*Temperature Observations off Ardlamont Point.*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date	20.4.86	19.6.86	6.8.86	25.9.86	16.11.86	29.12.86	7.2.87	11.5.87	15.6.87	12.8.87	24.9.87	3.12.87	13.2.88	23.3.88	20.9.88
No. of Pts.	7	4	7	7	6	6	4	6	10	10	4	6	6	6	6
Temp.	41·9	45·1	50·0	52·4	50·8	46·7	43·4	44·6	48·5	52·2	54·5	48·9	44·0	42·6	53·2
Slope	+2·3	+3·2	+6·1	+1·9	−2·5	−1·5	−0·8	+3·6	+9·8	+3·6	+1·9	0·0	−1·5	−0·6	+2·7

As the depth at the place of observation is only about 35 fathoms, it is unnecessary to note the thickness of the homothermic layer. The curves resemble the upper parts of those for Inchmarnoch, and, as a rule, show the characteristic homothermic type at the period of minimum, and clearly marked positive and negative slopes during the periods of rapid heating and cooling. Fig. 17, Plate XXV., shows a curious instance in which a very

abrupt inflection in the Inchmarnoch curve is repeated at the same position at the very bottom of the Ardlamont curve. This shows a remarkably horizontal arrangement of the isothermal sheets, as the stations are five miles apart. On this occasion there was no trace of extra heating in the shallow water; in fact, the Ardlamont temperature was lower than that in the centre of the open water. The upper 28 fathoms of comparatively warm water was resting very abruptly and over a large area on the colder mass below.

Observations off Skate Island.—The exact position is given by the bearing, centre of Skate Island, E. ½ S. 7 cables; and its depth 107 fathoms (Sections 16 and 19, C D, Plate 9 in Part I.) is the greatest of any part of the Arran Basin. It lies in the centre of the long depression which runs up the East Arran Basin, and is the deepest point in the whole Clyde Sea Area.

The average density of water at 60° F. was as follows:—

	Surface, 13 observations.	Bottom, 13 observations.
Mean . .	1·02446	... 1·02508
Maximum . .	1·02497	... 1·02530
Minimum . .	1·02373	... 1·02471
Average Percentage of pure sea-water . .	94·0	... 96·5

In the vertical section, during the period of observation, the proportion of pure sea-water was 96·0 per cent., or in a normal year 95·7 per cent.

In estimating the homothermic depth, given below, the total depth is assumed as 105 fathoms.

TABLE XIX.—*Temperature Observations off Skate Island.*

No. . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1
Date . .	28.8.78	21.9.78	25.6.79	29.7.85	28.8.85	27.3.86	19.4.86	21.6.86	10.8.86	17.9.86	26.9.86	16.11.86	29.12.86	7.2.87	28.3.87	10.5.87	15.6.87	16.6.87
No. of Pts.	13	11	14	4	7	9	10	7	19	7	19	15	12	12	12	15	15	15
Temp. .	51·0	53·2	43·7	50 (?)	49·7	41·3	41·6	44·3	47·3	49·8	49·8	51·2	47·2	44·5	43·8	44·3	46·6	46·8
Slope .	+9·4	...	+8·2	...	+6·6	0.0	+2·5	+3.3	+6·9	+7·1	+6·1	−1·8	−0·8	−0·4 (−1·0 +0·6)	−0·1	+2·0	+4·4	+5·6
H.D. .	0	...	75	...	35	105	85	85	55	20	0	85	85	100	105	95	45	85
h.t. . .	...	...	42·6	...	47·6	41·3	41·3	44·0	45·2	47·4	...	51·4	47·4	44·5	43·8	44·2	46·1	44·1

No. . .	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Date . .	7.7.87	8.7.87	31.7.87	14.8.87	16.8.87	12·9·87	22.9.87	18.12.87	2.1.88	7.1.88	15·2·88	28.2.88	22.3.88	6.4.88	14.4.88	16.5.88	5.6.88	19.10.88
No. of Pts.	14	11	17	12	11	6	12	18	12	9	15	9	15	9	6	12	9	15
Temp. .	47·1	47·5	49·0	49·2	49·7	?	51·2	47·7	46·5	46·3	44·6	44·2	42·9	42·6	42·5	43·4	44·1	49·5
Slope. .	+6·6	+7·0	+8·8	+6·3	+7·2	...	+4·9	−1·6	−1·2	−0·9	−1·1	−2·9	−0·3	+0·1	+1·5	+2·3	+4·2	+2·2
H.D. .	55	50	40	35	0	...	35	55	60	40	75	60	95	105	75	6	55	30
h.t. . .	46·2	46·2	46·5	47·2	...	...	49·2	48·1	46·9	46·7	44·8	44·9	43·0	42·6	42·3	43·0	43·0	48·6

The importance of the Skate Island observations is exceptional, for several reasons. Being the deepest water in the Clyde Sea Area, it is the part of the Arran Basin most completely cut off from the sea, and consequently the characteristic thermal changes of the Basin should here be most readily detected. The station was also important because, from some happily situated landmarks, the exact spot where observations were made could be readily picked up at any time, and any tendency to drift while observing could be at once detected and checked. A set of observations had also been taken by Mr J. Y. BUCHANAN in the summers of 1878, 1879, and 1885, thus allowing of some interesting comparisons.

The most striking feature of the temperature curves is that, with scarcely any exceptions, the lower 50 or 60 fathoms is straight and perpendicular, showing a predominating homothermic state in the deeper water.

There were positive slopes on twenty-three occasions, zero slope once, and negative slopes only ten times. Compared with the Garroch Head observations, this shows that negative slopes are more difficult to establish in the deeper water. Otherwise the two stations are very similar. The maximum positive slope observed, 9°·4, is very nearly the same as for Garroch Head. The maximum negative slope was 2°·9, and only on this one occasion was the negative slope greater than 1°·8, while the positive slope was only twice less than that figure. Positive slopes over 4°·9 occurred fourteen times,—twice in June, thrice in July, five times in August, and four times in September. Negative slopes were only found in the months from November to March; that is, in the months of rapid cooling and of minimum temperature. Positive slopes less than 4°·9 were shown three times in April, once in May, three times in June, and once in October; that is, at the commencement of the periods of heating and cooling respectively.

The rate of gain or loss of heat in the vertical section in a short interval of time could be studied on four occasions, when observations were made on successive days, or with an interval of a few days. Fig. 18, Plate XXV., shows curves 17 and 18 of Table XIX. representing the state of matters on the 15th and 16th June 1887. The observation of the 15th (curve A) was made at 12 o'clock, when the air-temperature was 57°·0, a light breeze was blowing from the north-west, and the tide was $4\frac{3}{4}$ hours' ebb. On the following day the observation was made at 15^h30, when there was a very light southerly breeze with air-temperature 63°·0, and the tide about half an hour's flood, practically at low water. The change of temperature does not seem to be due to the movement of warmer water, for the upwelling off Otter effectually isolates the surface layers of the Arran Basin from those of Loch Fyne, and, with the ebb tide, the effect of the warmer water in the seaward division could hardly be felt, although the fact of a distinct increase in surface-salinity on the second day hints that this might have been the case. The gain of heat, averaging nearly a degree for the first 20 fathoms (below which there was practically no change), may thus be taken to represent the heating effect of 21 hours' solar radiation, minus the cooling due to $6\frac{1}{2}$ hours of darkness; and supposing the average rate of gaining heat in sunshine to be the same as that of losing it at night, the result would

represent $14\frac{1}{2}$ hours of sun-work. The actual gain of temperature throughout the whole mass was 0°·2, so that the rate of gain of temperature of 0°·014 per hour for the whole depth of 105 fathoms, or 0°·070 per hour for 20 fathoms.

Fig. 19, Plate XXV., gives a similar pair of curves for 7th and 8th July 1887. The weather on this occasion was warm throughout, with a southerly or south-westerly breeze, interrupted by light squalls of hot air from the land. On the 7th, the middle of the observation was at 15^h0, when the air-temperature varied from 63° to 66° in the calms and squalls. On the 8th the observation was at 17^h15, and the air-temperature between 68° and 70°, the breeze also being fresher. The tidal phase was thus practically the same on both days ($1\frac{1}{4}$ hours' ebb on the 7th, $1\frac{1}{2}$ hours' ebb on the 8th), and the observations were $26\frac{1}{4}$ hours apart. Of this time there were 19 hours daylight and 7 hours darkness, but the sky was frequently clouded. The two curves are identical below 60 fathoms, and from 30 to 60 fathoms run parallel and very close, the later being about 0°·2 warmer. The upper 30 fathoms are very peculiar. If on the second occasion only three observations had been made, viz., at 2, 12, and 31 fathoms, the two curves would have been put down as exactly the same. The upper 30 fathoms of curve A form a perfect paraboloid—the characteristic curve of heating from above—except for a superficial cooling in the first 3 fathoms, which gives a sharp inflexion. The upper 2 fathoms of curve B complete the symmetry of curve A, but the rest of B is irregular, showing a curious local heating between 2 and 12 fathoms, and a much more marked increase of temperature between 12 and 30. The latter portion of the curve is indeed of the inverted type. It is difficult to estimate the average temperature of curve B, as there is scarcely a sufficient number of points in the upper part, but the increase of temperature seems to be about 0°·4. On the assumption mentioned above, this would correspond to a rate of heating for the whole depth of 0°·033 per hour of sunlight, more than twice that found for June. The soundings were, however, made in squally weather, and the irregular distribution of temperature layers on the 8th must be partly, perhaps mainly, due to the disturbing influence of a cross-channel breeze of hot air setting up irregular movements in the water.

Fig. 20, Plate XXV., gives the vertical curves for Nos. 22 and 23 of Table XIX., observed on August 14th and 16th, 1887. Curve A on the 14th represents the state of temperature at 19^h40 when a light north-westerly breeze was blowing, curve B on the 14th at 15^h15 when there was a very light breeze from the south-west. On both occasions the sun was shining brightly. The observations were 44 hours apart, of which 26 were in daylight and 18 in darkness. Except for a slight excess of heating at the surface, and an apparent cessation of heating at 30 fathoms, the two curves were similar in form and only slightly divergent. They were coincident at the bottom, and the later curve showed 2° of warming at the surface. Were it not for the inflexion of curve A at 30 fathoms, which almost suggests a misreading of the thermometer by one degree, the amount of heating would diminish steadily from surface to bottom. Curve B shows almost the greatest positive slope observed at Skate Island. The average

temperature of the vertical curve is greater by 0°·5 in B than in A. On the hypothesis of equal rates of heating and cooling in sunshine and darkness respectively, we find the rate of heating to average 0°·062 per hour of sunshine. This is twice the rate deduced for July, and four times that for June. It is impossible to believe that the heating power of the sun increases so enormously while its angle of incidence diminishes, and hence the hypothesis of assigning to local solar radiation the whole, or even a very large share, of the rise of temperature is obviously wrong. Probably the real determining conditions are very complex. They must indeed ultimately depend on radiation, but we must look for an explanation to the general radiation over the whole area involved, over land whence the heat is carried by wind and surface water as well as over the water itself. Light on the question of the process of thermal change may be looked for rather in the study of mass temperatures than of such linear temperatures as are here noted.

Figure 21, Plate XXVI., gives the one case observed of the rate of cooling in a short interval of time, and the interval is as much as five days. In January, of course, the duration of darkness was greatly in excess of that of daylight. In the case in question the time between the soundings contained 51 hours of darkness and only 21½ hours of light. The weather during the interval was usually overcast, with a good deal of rain and some southerly wind. On the 2nd the air-temperature was about 35°, on the 3rd about 44°, and on the 6th and 7th it rose in the afternoon to 49° or 50°. The great warmth of the later days is shown by a slight rise in temperature of the upper 10 fathoms; but from 20 fathoms to the bottom there is a steady fall, the earlier cold weather apparently having produced effects which were steadily and uniformly working down. The inversion of the climatic change in the air greatly reduced the negative slope of curve B, but the mean temperature was 0°·2 lower than that of curve A. Supposing, as before, that cooling by radiation proceeded at the same average rate in the dark as heating by radiation did in sunlight, and also that the total thermal change was due to radiation, the rate of cooling would appear to be 0°·007 per hour.. The disturbing causes are so numerous, however, as to deprive this conjecture of any quantitative value.

A cross-section was made on September 23rd from Laggan Bay, on the Cantyre side, across the deep trough to Skate Bay, on the Cowal shore. The day was hazy and dead calm, and there had been no wind to speak of for three days. The dry-bulb thermometer in air read 49°·2, the wet-bulb 49°·3. The tide was about low water, being at the end of ebb when the Laggan Bay observations were made, and at the beginning of flood when the Skate Bay soundings were taken. It was practically slack water all the time. It is remarkable that the isotherms (fig. 22, Plate XXVI.) dip strongly toward the eastern side throughout the entire depth of the water. The cause of this is not clear. There was no wind to set up a circulation; nor was the heating on the eastern side due to the action of the shallow water, for the dip of the isotherms commenced westward of the deepest sounding. There was the appearance of upwelling on the eastern side, and of sinking of surface water on the western. No explanation of the phenomenon presents

itself: if the isotherms indicate a shearing movement in the water, the only efficient cause seems to be the tidal current, which at the beginning of flood may have carried warmer surface water along the west side, but this would not account for the westward dip of the deepest isothermal sheets.

The larger seasonal effects, as shown at the Skate Island station, may be best brought out by grouping the curves of each year so as to show the stage of heating and cooling arrived at at certain definite dates as equally spaced as possible. For this purpose it would be very important to have curves smoothed by taking the average of two at a short interval apart, but this is only possible in the cases cited above. Where exact averages cannot be obtained, the curves may sometimes be smoothed, in a manner not altogether arbitrary, by combining neighbouring observations, and when this is done the fact will be mentioned in the description.

Figures 13 to 15 on Plate VII. show the results for the three seasons, corresponding curves being similarly coloured. The dates to which the various curves correspond are as follows:—

TABLE XX.—*Typical Vertical Temperature Curves off Skate Island.*

Curve.	Type.	1886-87.			1887-88.			1888.		
		No. in Table XIX.	Mean Date.	Time Interval.	No. in Table XIX.	Mean Date.	Time Interval.	No. in Table XIX.	Mean Date.	Time Interval.
I	Minimal, . .	6	27 March	23 days	15	28 March	43 days	31	22 March	39 days
II	Early Heating, .	7	19 April	63 ,,		10 May	37 ,,	Mean 33, 34	30 April	36 ,,
III	Rapid Heating,	8	21 June	78 ,,	16 Mean 17, 18	16 June	80 ,,	35	5 June	136 ,,
IV	Maximal, . .	Mean 9, 10, 11	7 Sept.	70 ,,	,, 23, 25	4 Sept.	112 ,,			
V	Early Cooling, .	12	16 Nov.	43 ,,				36	19 Oct.	
VI	Later Cooling, .	13	29 Dec.	40 ,,	,, 26, 27	25 Dec.	59 ,,	...	...	...
VII	Final Cooling, .	14	7 Feb.		,, 29, 30	21 Feb.		...	...	

The correspondence in date is not very close, but all the curves having the same number show a similar form, and belong to the same type. The first year is the most characteristic, and may be taken as generally typical of the order of temperature changes at this station. While the forms of the curves in different years are substantially the same, the position in temperature varies considerably. To some extent, this may be explained by the want of an observation at the actual date of maximum or minimum, but there is also a difference due to the different thermal amplitude of each season.

The critical points, where one curve changes into another, are described in some detail for Garroch Head; see figs. 12 to 15, Plates XXIV. and XXV. The minimum in each case is typically homothermic, and No. 2, the curve of early heating, is derived from it by a scarcely perceptible or quite imperceptible change in the lower layers, but a marked positive

divergence in the upper 30 fathoms, showing a distinct paraboloid form, except that the upper end shows the 5-fathom layer of warmest water to be comparatively uniform in temperature. No. 3 shows homothermic heating throughout the whole depth below 20 or 30 fathoms, the straight vertical curve being pushed forward nearly 3° in 1886 in 63 days, 2° in 1887 in only 37 days, but only about 0°·5 in 1888 in 36 days. The upper part of the curve is typically paraboloid, diverging positively from parallelism with the preceding curve toward the upper end. In 1888, however, the upper end presented an inverted paraboloid form; which, together with the much slower rate of deep heating, showed some exceptional retardation in the progress of annual change. This may be related with the air-temperature (see curves, fig. 3, Plate XXII.), which was practically the same in 1887 and 1888 for April and May, but in June was nearly 5° lower in 1888 than in the preceding years. This lower air-temperature, or the causes which produced it, would account for the inversion of the upper part of the 1888 curve, but not for the slow rate of homothermic heating, which must be otherwise explained. In large part, the closeness of the three curves is due to the exact minimum not being represented. Curve 1 shows cooling still in progress, and curve 2 heating from the surface, while the lower part is colder than in 1. Curve 3 in 1887 shows a distinct approximation to the sickle shape. The intermediate minimum indicates that the rise of temperature had been less rapid at 50 fathoms than anywhere else. If, as it seems reasonable to assume, homothermic change of temperature is effected by the complete vertical mixing of the water throughout the homothermic depth, while the positive or negative heterothermic condition of the upper layers is produced by positive or negative surface heat-exchange taking place too rapidly to be equalised throughout the mass by the movements in progress, it would appear that there was a freer circulation in the lower than in the upper half of the mass of water. This might result from a peculiar arrangement of the salinity of the water, or from a peculiarity in wind disturbance, but, unfortunately, no intermediate samples of water were collected on the occasion. In curve 4 we see the typical paraboloid form of a rapid rise of temperature through surface-heating. The homothermic condition has been entirely overcome, and from bottom to surface the water grows warmer more and more rapidly. Curve 5 (only properly shown for 1886) marks the passage of the annual maximum. The curve is negative, for rapid surface-cooling has set in, and it approximates to the sickle shape possibly because heat is still being passed down by conduction in sufficient amount to partially overcome the tendency to homothermicity. The slope is, however, very slight. The curve in question shows a check to surface-cooling at the time of observation by the very slight slope of the upper 10 fathoms. Compared with curve 4, it shows most rapid cooling to have taken place at the surface, and most rapid heating at the bottom, while at 17 fathoms the temperature was the same in both cases.

The process of transition between the forms 4 and 5 is of very great interest, and may be indicated thus. Until the equinox, there is a large positive gain in the surface heat exchanges of the water by solar radiation, and until about the middle of August by contact with warm air. The surface density being much lower, through its less salinity,

than that beneath, the effect of evaporation in this climate is not sufficient to increase the density through increasing salinity so much as the increased temperature reduces it. Hence the hottest surface layer tends to float and become still hotter, giving a very steep positive slope to the curve. The mass of the water tends toward homothermicity by the mixing effect of direct and indirect wind and tidal action, but the conduction of heat downward from the warm, highly heterothermic surface layer gradually raises the temperature, reducing the heterothermic layer, and giving a positive slope to the whole curve. The greater the positive slope the more rapid is the flow of heat downward by conduction, and the curve of density *in situ* becomes similar to a mirror image of that of temperature, thus assuming a stable form and retarding the mixing processes which involve vertical circulation.

The mean difference of density determined at 60° F. between the surface and bottom water at Skate Island was −0·00052, the bottom being denser. This corresponds to the ordinary state in homothermic conditions. For the maximum positive temperature slope observed, viz., 9°·4, this difference is increased to −0·00219; while for the greatest negative slope observed, viz., 2°·9, the difference is −0·00018. In the latter condition it is apparent that the resistance to vertical movement on account of the density of the layers, due to salinity and temperature, is less than one-tenth as great as in the former, and a very slight increase of surface density would determine a downward convection current. Inasmuch as the slope of a curve is estimated from the average temperatures of layers of five fathoms thick, it is plain that the actual surface layer must often be cold enough to cause an inversion of the density gradient and lead to downward convection in a place like Skate Island, where the salinity gradient is so very slight. These considerations fully explain the small negative slope, the parallelism, and the rapid displacement negatively of the four curves for cooling, Nos. 5, 6, 7, and No. 1 of the next year.

The thermal conditions of themselves would bring about an approach to homothermicity, and they are here reinforced by the other agents working in that direction—the action of wind and tide.

The time-changes of temperature are shown in fig. 1, Plate II., in the same way as for Garroch Head, only, on account of the smaller number of observations, the horizontal scale is reduced one-half. It closely resembles the Garroch Head diagram. The isotherm of 50° was reached by the surface on July 8th, 1886, and had worked its way to the bottom by October 28th. In cooling, the temperature of 50° was reached by the surface on November 8th, and on the bottom by November 30th, the isotherm, which required 110 days to work down in rising, requiring only 21 days to work down in falling. Gauged by this isotherm, the warm season at the bottom was one month, while on the surface it was four. The isotherm of 54° reached the deepest point (7½ fathoms) on September 15th.

In 1887 the surface was above 50° from May 28th to November 6th, a period of 5 months and 10 days, but the isotherm of 50° never reached the bottom at all, its utmost penetration being to 62 fathoms on September 24th. The isotherm of 54° reached 8

fathoms, its deepest point, on August 1st. This failure of the heat to penetrate in 1887 is very remarkable, as the water-temperature at the preceding minimum had not been so low as the year before, and the unprecedented heat of June might be expected to have a great effect. The Garroch Head diagram shows no trace of this effect; and the only hint conveyed is by the tendency of the June 1887 vertical curve to assume the sickle shape. The temperature section for June (No. X., Plate X.) shows a large mass of cold water at the head of the Central Arran Basin, tapering away off Skate Island, and disappearing a little south of Inchmarnoch. By July this had disappeared. The existence of the intermediate layer of cold water, however, shows that the usual vertical movements leading to mixture and equalisation of the temperature in the lower layers had by some means been restricted. The density affords no clue to the cause of this, as the water, both at surface and bottom, was considerably above the average, and the difference between them was very much less than usual. The calmness of the season might be brought forward to explain the effect, but this should have produced an even more marked appearance of the intermediate minimum in Loch Fyne, where none was observed. From the incomplete data for 1888, it seems to have been a year resembling 1887, except that the maximum bottom temperature was even lower.

Observations off Kilfinan Bay.—The soundings were made in the axis of the Arran Basin, off Kilfinan Bay, Otter House bearing E. 2 miles 2 cables, and the depth 80 fathoms. About this position the depths are very irregular, but for 14 miles down the Basin there is never less than 75 fathoms in the centre. The density of the water was only occasionally observed, but we may assume it as intermediate between Skate Island and Otter I.

The curves resemble those for Skate Island, though somewhat less regular, and it is unnecessary to discuss them farther in this place.

TABLE XXI.—*Temperature Observations off Kilfinan Bay.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11	12
Date . .	29.3.87	10.5.87	15.6.87	7.7.87	15.8.87	23.9.87	16.12.87	3.1.88	14.2.88	22.3.88	4.6.88	19.10.88
No. of Pts. .	9	12	9	9	12	9	12	12	9	9	12	9
Temp. . .	43·9	44·6	46·6	47·8	49·6	51·7	48·1	46·6	44·8	43·2	44·8	49·9
Slope . .	+0·2	+2·0	+4·4	+5·8	+5·8	+4·9	- 2·7	- 0·9	- 1·0	- 0·9	+4·7	+0·1
H.D.* . .	75	55	35	20(?)	0	0	35	25	65	60	30	75
h.t. . . .	43·9	44·3	45·2	46·3	...	...	48·9	46·8	44·9	43·3	43·2	49·9

* Depth assumed as 75.

Observations at Otter I.—Observations were usually made with Otter Beacon bearing N.E. by E. 7 cables, where the depth was 30 fathoms. This point was just outside Otter Spit, where the tide runs strongly into and out of the Gortans Basin of Loch Fyne.

Observations were, however, often made nearer the entrance and farther from it. The average density of the water was as follows :—

	Surface, 5 observations.		Bottom, 5 observations.
Mean, ...	1·02461	...	1·02497
Maximum, . . .	1·02486	...	1·02507
Minimum, . . .	1·02416	...	1·02470
Average percentage of pure sea-water, ...	93·0	...	95·7

In vertical section, 95·2, or in normal year, 94·9.

TABLE XXII.—*Temperature Observations at Otter I.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11	12
Date . .	19.4.86	21.6.86	10.8.86	11.8.86	28.9.86	17.11.86	29.12.86	4.2.87	29.3.87	10.5.87	15.6.87	7.7.87
No. of Pts. .	7	7	7	4	4	6	6	6	6	3	6	7
Temp. . .	42·0	44·1	49·9	50·4 (?)	51·9	50·8	47·4	44·7	44·1	45·8 (?)	47·4	49·9
Slope . .	+1·6	+1·8	+2·9	+2·1	+0·9	−1·3	−1·7	−1·5	+0·3	+0·5	+3·2	+3·1
Depth . .	38	33	25	14	15	15	28	53	33	15	20	22

The main interest of this station arises from its position on the seaward side of the steep barrier which shuts off Loch Fyne from the Arran Basin. The discussion of density observations showed that there is a marked upwelling of deep water about this point, and temperature observations amply confirm the fact. The evidence from surface temperature will be given when speaking of Loch Fyne, but the clearest proof is shown by the rise of the isotherms to the surface at Otter on the temperature sections (Plates VIII. to XV.)

The effect of the tidal current running north up the wide Central Arran Basin, and finding no outlet except the narrow entrance of Loch Fyne to the north-east, seems to be to drag the deep layers of water up the slope, and so give rise to a back-flow on the surface, or in the still deeper layers. It is largely to this disturbance of the equilibrium of the mass of water in the Arran Basin, and to the similar action of other sloping shores, that I am inclined to attribute the continual mixing, which tends to maintain a homothermic state in the deep water. The tidal reaction-currents would naturally be powerfully reinforced by wind, and possibly modified to some slight extent by variations in density.

Temperature Sections of the Arran Basin.—The outstanding features of the mass distribution of temperature on eighteen trips were laid down in the form of isotherms upon a much exaggerated profile of the section from the Channel through the East and Central branches of the Arran Basin and Loch Fyne to Cuill. These sections, coloured according to the principle already described, are useful in showing the nature

and order of the changes going on. The observations were, however, so few that when the great extent of the Arran Basin and Plateau are considered it appears impossible to utilise the sections for any reasonably accurate measurement of the mean temperature of the region, and accordingly I do not reproduce the calculations provisionally arrived at, and published in 1887 * in a preliminary paper dealing with the first year's work. An attempt was made to allow for some of the probable errors in an estimate of this kind, but the result was unsatisfactory. In the case of the narrower divisions, however, the necessary allowances could be made, and they are discussed in detail. The sections, which are practically those of the Arran Basin and its neighbouring regions, are given in Plates VIII. to XI. The following is a brief summary of the main features:—

1. *April* 1886.—The only isotherms shown on the section are those of 43° and 42°; beneath about 15 fathoms the temperature varied from 42° to 41°·5. The section presents a perfect picture of the uniform minimum temperature just beginning to rise at the surface.

2. *June* 1886.—Regular warming is here shown from above downward, and still more markedly from the ocean inward. The isotherms all dip strongly seaward, showing the effect of the warm Channel water forcing its way into the Arran Basin. The Central Arran Basin is much colder than the Western Branch at the same depth, and there is an evident up-draught of cold water from below at Otter.

3. *August* 1886.—The same general order of temperature distribution is clearly shown. Warming is still taking place from above downward, and from the sea inward, the deeper isotherms showing an obvious relation to the irregularities of the bottom. The up-draught at Otter does not appear to affect more than the superficial 30 fathoms.

4. *September* 1886.—The conditions here are similar to those in the August section, perhaps a little more pronounced, on account of the higher temperature of the surface water.

5. *November* 1886.—Here rapid cooling is shown. The Channel water being homothermic at 50°, is rapidly chilling the lower layers of the deep water of the Arran Basin, which remains above 51°, but the Channel water is warming the surface of the Arran Basin, which has fallen below 50°, and is colder toward Loch Fyne. The upwelling at Otter is marked by the warm deep water coming nearest the surface at that point and overflowing into the Gortans Basin of Loch Fyne, which, at the bottom, is warmer than any other water at the same depth.

6. *December* 1886.—Here rapid cooling has gone on in the Arran Basin from the surface down, most rapidly in the centre. The Channel water not having cooled so fast, is now warmer than that of any part of the Basin, and the isotherms at the mouth of the Arran Basin dip landward. In November the Channel water was aiding seasonal change, and by its high salinity and low temperature rapidly affected the whole Arran Basin. But cooling by surface exchange, and downward convection has now outstripped it, and the Channel water is left relatively warmer, feebly retarding the inevitable work of advancing winter. At the head of the Basin the isotherms dip seaward, showing the

* *Proceedings*, Glasgow Philosophical Society, xviii. (1887), 332–356.

up-draught of the warm bottom layer raising the temperature of the upper strata. At this end of the Basin the last remnant of water as warm as that of the Channel is found, an interesting instance of the effect of configuration.

7. *February* 1887.—Here we find that the Channel water has again cooled down below that of the Arran Basin and is chilling it rapidly from the sea, while surface cooling at the upper end of the Basin seems relatively retarded. This effect may perhaps be accounted for by the middle of winter being the rainiest season, and February the month of minimum surface salinity. Hence in February 1887 (and the condition was similar in November 1886) the density gradient offered unusual resistance to downward convection, sufficient to restrict the operation of cooling from the surface to downward conduction and the chance action of wind. On this account the Channel water, cooling steadily, is once more furthering seasonal change by mixing, in virtue of its higher salinity, with the Arran Basin water.

8. *March* 1887.—The minimum has now passed. It was not so low as in 1886, and Loch Fyne did not come to so low a temperature as the Arran Basin, another important difference. Now the Channel has warmed up rather more than the mass of the water in the Basin, on which, however, it seems to have produced little effect. The surface water of the Basin is also warming by surface exchange of heat, and the last remnant of the warm deep layer appears at the head of the Arran Basin as it did in December 1886.

9. *May* 1887.—Heating has here proceeded gradually from the surface downward, and from the ocean inward. At the Skate Island sounding and also in Loch Fyne there was evidence of a patch of lower temperature surrounded by warmer water. The appearance suggests that the vertical movements of circulation follow more or less the configuration of the bottom, descending from the Plateau to the deepest part, creeping up the slope at the head of the Basin, and returning seaward in the upper layers. This rotation of the water in a vertical plane, if it exist, would account for a portion of colder water being left in the centre.

10. *June* 1887.—Here we see a much higher temperature throughout than in the previous June, and a more marked heterothermicity in the water. The surface stratum of warm water deepens in a very characteristic way when it passes from the practically homothermic Channel to the centre of the West Arran Basin, and then runs away rapidly in the Central Arran Basin, deepening again over Loch Fyne. The peculiar condition of the Plateau on this occasion is treated in detail on p. 24. The equally interesting mass of cold water, resting against the slope at the head of the Arran Basin, and melting away into warm water above, below, and seaward, has been remarked on at p. 23. We may look on this wedge of cold water as the dwindling mass attacked equally by the in-draught from the seaward and warmer parts of the Arran Basin from beneath and by the downward conduction of heat from above. From some cause which does not appear, the customary upwelling along the terminal slope does not seem to have occurred, and so the cold mass has not been entirely isolated as in May.

11. *July* 1887.—Apparently more influence is exerted in this section by downward conduction from the hot surface layers than is usual. The up-draught at the head of the Basin is less marked, and at the mouth of the Basin the cold deep water seems to be upwelling and creeping across the Plateau under the mass of warm Channel water, which, pouring into the Basin, produces its customary heating effect a little beyond the position where that effect usually begins to be noticed.

12. *August* 1887.—Except for its higher temperature, this section closely resembles that for August 1886. In both, the deep water of the West Arran Basin has been raised above that of the central branch at the same depth, but in this the effect of the warm Channel water cannot be so clearly traced, because no observation was taken on the inner edge of the Plateau. The upwelling at Otter is very clearly marked.

13. *September* 1887.—This corresponds closely with the section for September 1886. It shows the temperature at the actual maximum observed at the time when the warm salt water of the Channel was producing its maximum effect throughout the Basin. The manner in which the ridge off Loch Ranza abruptly separates the deep water of the western branch from that of the central is exceptionally well brought out. It is interesting to note that some less complete sections which were drawn through the East Arran Basin show a marked similarity to the series now being described. Although there is no bar across the deep channel which runs from off Largybeg to off Kilfinan Bay, the upper section of the Basin shows every mark of isolation in the slower response to temperature change, a result due solely to distance from the powerful influence of the Channel water.

14. *December* 1887.—This section illustrates best the utter uselessness of isotherms to delineate temperature distributions when the range is small. Here the whole mass of water is almost homothermic at 48°, the isotherms of 47° and 49° only appearing for a short distance at the head of the Basin. The Channel was much warmer than the Arran Basin, and except in Loch Fyne surface-cooling was being propagated directly throughout the mass of water.

15. *January* 1888.—Here there is a somewhat unusual distribution of temperature. The surface of the Arran Basin is cold, the cold layer being thinnest at the head where the Otter upwelling raises warmer water, and thickest on the Plateau which it completely covers, cutting off the warmer homothermic water of the Channel from that of the deep parts of the Basin.

16. *February* 1888.—The water on the Plateau appears to continue colder than that on either side, the greater part of the Arran Basin being filled with nearly homothermic water of the same temperature as that in the Channel, the process of cooling having evidently gone on unchecked by the usual freshening of the surface water.

17. *March* 1888.—Considerable cooling had gone on since February, and the resulting distribution of temperature is curiously irregular. The temperature on the Plateau was again lower than that on either side, and it had exercised a strong cooling effect on the neighbouring parts of the Arran Basin. At the head, on the Otter slope, there was an area of considerably warmer water, resembling on a smaller scale the arrangement shown

in June 1887. Looking at the section generally, the Plateau as a whole seems a centre of cold, on receding from which to the north and the south along the surface—and still more rapidly on deeper planes—the water grows warmer. The rapid cooling since February, the very low temperature of both these months, and the absence of a layer of very cold surface water, point to the great part which must have been played by downward convection caused by increase of density by chilling in the surface layers.

18. *April* 1888.—Here again, as in the whole series of the winter 1887–88, the coldest water radiates from the inner slope of the Plateau. The difference in temperature is, however, very slight, and the conditions closely resemble those of April 1886, the water being practically homothermic, and the mean temperature almost the same in the two occasions. It represents the typical arrangement of minimum temperature.

The succeeding temperature trips were not sufficiently systematic to allow of the observations made during them being utilised for drawing sections.

In order to compare the distribution of temperature with depth in the eastern and western branches of the Arran Basin, the diagram fig. 23, Plate XXVI., shows the Skate Island sounding (S) in the centre, with the isotherms connecting it to Inchmarnoch (I) and Brodick, East Arran Basin (B) drawn to the right, and those connecting it to Inchmarnoch and Carradale, West Arran Basin (C) to the left. The profile is approximate only. If the section were folded along the line of the Skate Island sounding, and then folded in the opposite direction along the two Inchmarnoch lines, as shown in the figures at the lower left-hand corner of fig. 23, the run of the isotherms would show the true relations of the two southern branches, while the central part would carry on the lines up the northern branch of the Basin. Fig. 23 shows that, in June 1887, the Eastern Branch was, at the same depths, considerably colder than the Central. It also shows how the included wedge of cold water (see longitudinal section for June) stretches in a rapidly-thinning slice as far as Brodick in the Eastern branch, but does not enter the Western branch at all. It is thus seen to be purely a product of the configuration of the Central branch of the Basin.

Fig. 24, Plate XXVII., is a similar diagram for September 1887, and is even more instructive,—the sounding off Loch Ranza, on the ridge separating the Western from the Central trough, being inserted. Down to 50 fathoms, or practically to the level of this ridge, there is little difference between the Eastern and Western branches, both being somewhat warmer than the Central, but beneath 50 fathoms the effect of configuration is brought out in a most interesting manner. The temperature of 51° scarcely occurs in the Western branch, and 50° does not enter it at all, although that isotherm runs up the Eastern and Central branches at an average depth of 63 fathoms. Below 80 fathoms the temperature in the Eastern branch is below 49°, and this reaches to Inchmarnoch, accounting for the curious patch of cold water in the section for September 1887 (No. XIII. Plate XI.), but the Central Basin remains warmer throughout, the lowest temperature in the Skate Island Depression being 49°·1.

Seasonal Range of Temperature in the Arran Basin.—The mean temperature curves for seasonal change at each of the Arran Basin stations were drawn on a large scale, and combined with a view of getting the true mean annual movement of temperature for the whole mass of the deeper water. The curves for Largybeg, Brodick, and Garroch Head were drawn on one sheet, time being abscissæ, and temperature ordinates. A mean curve was drawn freehand through the points determined, mainly the very numerous points of the Garroch Head curve. This gave an approximation to the mean annual conditions of the East Arran Basin, so far as regards the mass of the deep water, the curve embracing two maxima and three minima.

The curves for Inchmarnoch, off Loch Ranza and Carradale, made a second though less complete set, the mean drawn through which followed most closely the Carradale points, and this may be taken as typical of the West Arran Basin.

Finally, the curves for Skate Island, Kilfinan, and Otter I. were combined graphically on a third sheet, and represented the conditions of the Central Arran Basin. The three mean curves were then traced off on the same piece of tracing paper, with different coloured inks, and a mean, drawn by eye through the three, was taken as representing the seasonal change of temperature of the mass of the deep water of the Arran Basin as a whole.

TABLE XXIII.—*Monthly Mean Temperature of Mass of Water in the three Divisions of the Arran Basin from Curve.*

Station.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1886.												
Arran B. East	...	...	...	42·2	44·0	46·0	48·4	50·6	51·9	51·5	49·6	46·1
„ West	...	...	...	42·4	43·8	45·6	48·2	50·1	51·2	51·2	49·7	47·1
„ Central	...	...	...	42·3	43·4	44·8	47·2	49·3	50·6	51·0	49·8	47·4
„ Mean	...	...	...	42·3	43·5	45·3	47·7	49·9	51·3	51·4	49·7	46·7
1887.												
Arran B. East	43·9	43·5	43·4	44·3	46·2	48·4	50·9	53·0	53·0	51·4	48·4	45·9
„ West	44·4	43·5	43·6	44·8	47·0	49·6	50·9	52·0	52·0	50·7	48·7	46·5
„ Central	44·9	44·1	43·8	44·2	45·6	47·4	48·7	50·4	50·8	49·6	48·5	46·7
„ Mean	44·5	43·7	43·5	44·4	46·2	48·4	50·2	52·0	52·1	50·4	48·5	46·3
1888.												
Arran B. East	44·6	43·2	42·0	42·8	...	...	...	...	...	...	...	...
„ West	44·6	42·8	42·3	42·8	...	...	...	...	...	...	...	...
„ Central	45·4	44·0	42·6	42·8	...	...	...	...	...	...	...	...
„ Mean	44·8	43·4	42·3	42·8	...	...	...	...	...	...	...	...

The East Arran Basin shows the greatest range of temperature and a slightly earlier phase than the others. This is brought about by a higher maximum, all the curves coming close together at the minimum. At the maximum the curves are most widely separated, the West Arran Basin coming second in each case, and the Central branch last. The three curves preserve this order during the annual rise of temperature, but reverse it while falling and at the minimum, when the Central branch is warmest and the Eastern coldest. The curves cross in April while the temperature is rising, immediately after the minimum, and in October or November when falling, shortly after the maximum. The mean temperature for each month, taken from the curve, is given for the branches and the Basin as a whole in Table XXIII.

Fig. 25, Plate XXVII., showing the seasonal variation of the temperature of the air as the average of the whole Clyde Sea Area, of the whole mass of water in the Arran Basin, and of the superficial layer of 5 fathoms, may be usefully compared with fig. 5, Plate XXIII., giving the same data for the Channel. It must be remembered, however, that although the Arran Basin results are supported by much more numerous data than those of the Channel, the regular homothermic change in the Channel makes its curve probably more correct than that of the Basin.

Comparing the temperature of the whole mass of water, we see that it started on April 15th, 1886, from the same minimum as the Channel, 42° ; and on October 1st it reached its maximum value of 51°·6 (3°·4 lower than the Channel, and twenty days later). This rise of 9°·6 in 165 days corresponds to a mean storage of 0°·058 per day, one-third less than the Channel rate. The rate of fall of temperature increased much more gradually than in the Channel. By March 1st, 1887, the minimum temperature, 43°·6, was reached, slightly lower and a little earlier than the Channel. This corresponded to a loss of 8° in 151 days, or at the rate of 0°·053 per day, a rate one-fifth less than that of the Channel. On September 2nd, 1887, the maximum of 52°·2 was reached (4° colder and 16 days earlier than the Channel), a rise of 8°·6 in 186 days, at the rate of 0°·046 per day, the ratio to the Channel conditions being the same as in the previous year. The fall of temperature proceeded more gradually, the minimum, 42°·5, being reached on March 20th, 1888, 9°·7 being lost in 199 days, or at the rate of 0°·049 per day.

The near approach to equality in the time of heating and cooling of the mass of water in the Arran Basin is remarkable when compared with the disparity shown in the Channel.

	Warming 1886.	Rate.	Cooling 1886.	Rate.	Warming 1887.	Rate.	Cooling 1887.	Rate.
Channel, . .	147 days,	+0°·090	171 days,	0°·065	189 days,	0°·065	217 days,	0°·062
Arran Basin,	165 days,	+0°·058	151 days,	0°·053	186 days,	0°·046	199 days,	0°·049

The rate of change of temperature in the Arran Basin varied, as the curve shows, more regularly and uniformly than in the Channel. Whereas the periods of heating and cooling in the Channel were as 100 to 115 on the average of two years, they were equal on the average in the Arran Basin. The minima were synchronous, but the

maxima occurred about a month later in the Basin. The curve of air-temperature cut that of mean water-temperature rather after the maximum, instead of before it, as in the Channel.

During the period of rising temperature, the air was warmer than the surface layer of water for 147 days in 1886 and for 125 in 1887; while the air was cooler than the water on 224 days in the cool season 1886–87, and 232 days in 1887–88, giving an average of 134 days of air warmer than water and 228 cooler, comparing with 134 warmer and 237 cooler for the Channel, the cycle being somewhat over a year in this instance.

The surface-water curve in fig. 24 is compiled in a less satisfactory way than the curve for mass temperature. It is nearly a mean between the mass curve and the air curve during the period of heating, and shows a tendency also to occupy an intermediate position at the minimum. During cooling, however, the surface and mass water curves coincided in 1886, but the surface curve remained higher until near the minimum in 1887. The former is probably the more characteristic form.

Interpolating probable values for the first three months of 1886, we are able to arrive at the following averages for the year:—

In 1886, . .	Air = 46·2	...	Surface Water = 47·4	...	Mass of Water = 46·4
In 1887, . .	Air = 47·0	...	Surface Water = 49·3	...	Mass of Water = 47·5

The "surface" water being the top layer 5 fathoms deep.

Here we see the mass of the water on the average of two years one-third of a degree warmer than the air, while the surface water averaged 1°·7 warmer, thus closely approximating to the condition in the Channel. It appears that on the average of the whole year the Arran Basin exercises a warming influence upon the air, although not to such an extent as the Channel.

Loch Fyne.

Loch Fyne is an extension of the Central Arran Basin so far as surface water is concerned, but the depressions of which it is composed are barred off in such a way as to isolate the deeper water more completely than in any other part of the Area. It may be said that the deep water of Loch Fyne is more effectively isolated from the Arran Basin than the Arran Basin is from the open sea. Within the Otter Bar the bed of Loch Fyne deepens into the comparatively flat and shallow Gortans Basin scarcely more than 34 fathoms deep, which in turn is shut off from the deep Upper Basin by a ridge at Minard, on which rises a series of islands separated by narrow channels. Beyond this second barrier there is a steep descent to depths of over 75 fathoms, and then a gradual rise to the head of the loch at Cuill. Numerous observations were made in Loch Fyne, and both temperatrue and density were more fully studied there than in any other division of the Area of equal size. Each station has a certain individuality with regard

to the movements and thermal changes of its water, and the form and variations of the temperature curves are of some interest. Speaking broadly, one would expect from the configuration that Loch Fyne should differ physically from the Arran Basin in the same way as the Arran Basin differs from the Channel, but to a greater degree.

It is to be noted that I restrict the name "Loch Fyne" to what is sometimes called Upper Loch Fyne. On ordinary maps and on the Admiralty chart the name is marked as it is popularly applied to the whole surface of water stretching northward from Inchmarnoch, thus including the Central Arran Basin.

Observations at Otter II.—The station termed Otter II. has Otter Beacon bearing S. by E. 2 cables, depth 20 fathoms. (Section 18 K, Pl. 9 of Part I.) It is just inside Otter Spit, where the tide runs very strongly, and on the sill of the Gortans Basin. The average density of water at the station is as follows:—

	Surface, 4 observations.		Bottom, 4 observations.
Mean, ...	1·02434	...	1·02479
Maximum, ...	1·02483	...	1·02498
Minimum, ...	1·02383	...	1·02451
Average percentage of pure sea-water,	93·0	...	95·7

In vertical section 95·2, or in normal year 94·9

The water is thus considerably fresher than that of Skate Island in the Arran Basin.

TABLE XXIV.—*Temperature Observations at Otter II.*

No.	1	2	3	4	5	6	7	8	9	10	11
Date	10.8.86	17.11.86	5.2.87	10.5.87	15.8.87	23.9.87	16.12.87	3.1.88	14.2.88	22.3.88	16.10.88
No. of Points . .	7	6	3	6	8	6	6	6	6	6	6
Temp.	50·3	50·0	44·3	45·4	52·0	53·2	46·7	46·1	44·4	42·9	49·9
Slope	+2·8	−1·1	−0·3	+1·4	+2·5	+1·5	−0·8	−0·3	−0·3	−0·9	−0·3

The temperature curves are usually straight or else very irregular, and this is also the case to a less extent at Otter I. The appearance is largely due to the difficulty of keeping station in the tideway, and the consequent uncertainty of taking two consecutive soundings in exactly the same spot.

The greatest positive slope shown was 2°·8, and the greatest negative slope −1°·1. The usual sequence of forms was shown, the homothermic, usually with a negative tendency, preponderating at the minimum. The curves of heating were usually rather irregular paraboloids, but No. 4 was a good example of an inverted curve. The best specimen of a contorted curve was No. 6, which occurred at the maximum of 1887, and showed alternate strata from the surface downward of warmer and colder water (fig. 26, Plate XXVIII.).

In 1886, a number of surface temperature observations were made in passing Otter

Beacon.* They were made as rapidly as possible in buckets of water drawn for the purpose at intervals of a minute, or in some cases less. On April 19, while passing up the loch in the "Medusa," we observed between 15^h12 and 15^h25, passing the Beacon at 15^h22. The tide at the time was about half-ebb, running out of the loch with about its maximum velocity. At 15^h12 the surface temperature outside Loch Fyne was $43^\circ{\cdot}4$, and this diminished to $42^\circ{\cdot}9$, $43^\circ{\cdot}0$, $42^\circ{\cdot}7$, $43^\circ{\cdot}0$ (at $15^h16\frac{1}{2}$), 18, $18\frac{1}{2}$, $19\frac{1}{4}$, then remained at 43° until 15^h22, when at the Beacon it rose to $43^\circ{\cdot}2$, and retained that value throughout the Gortans Basin. Here the ebb tide produced a perceptible cooling of the surface water just outside the loch, the total amount being about half a degree, indicating an upwelling of the slightly colder lower layers.

On June 22nd, 1886, observations were made at longer intervals coming down the loch. A surface reading was taken every ten minutes from 14^h50 to 15^h40, passing the Beacon at 15^h20, within an hour of high tide, the current setting in slowly. The resulting readings were :—

Beacon.

N.E. $47^\circ{\cdot}9$, $47^\circ{\cdot}0$, $46^\circ{\cdot}5$, $45^\circ{\cdot}7$, $45^\circ{\cdot}0$, $46^\circ{\cdot}7$. S.W.

The minimum occurring, as before, outside the loch entrance.

The soundings on June 21st (see Loch Fyne, Section II., Plate XII.) bring out an exactly similar distribution as prevailing at 15^h25, with the tidal phase rather more than an hour earlier, and a stronger current consequently running in.

On August 10th at 16^h20–17^h0 a set of surface temperatures was taken which showed a fall from $52^\circ{\cdot}1$ to $51^\circ{\cdot}3$, and a rise to $52^\circ{\cdot}2$ in passing the Beacon; although a mile further up the loch, the temperature again fell to $51^\circ{\cdot}6$. The tide was $1\frac{1}{2}$ hours flood, setting in strongly.

On the following day about 16^h0 the observations were repeated in leaving the loch, with the tide about low water, and the fall of surface temperature was found to be from $52^\circ{\cdot}5$ to $51^\circ{\cdot}6$, with a subsequent rise to $52^\circ{\cdot}6$ outside. (See Section III., Plate XII.).

On September 26th the Beacon was passed going up the loch at 15^h6. Observations every ten minutes for an hour previously showed a uniform surface temperature of from $53^\circ{\cdot}4$ to $53^\circ{\cdot}2$ to prevail all the way from Kilfinan Bay, but at 15^h8 it dropped to $52^\circ{\cdot}9$; then at intervals of ten minutes going up Loch Fyne the readings were $53^\circ{\cdot}0$, $53^\circ{\cdot}0$, $52^\circ{\cdot}9$, and $52^\circ{\cdot}7$. Here all that was shown was that the surface water in Loch Fyne was about half a degree colder than that outside, the slight change taking place at the entrance. The day was calm and dull, the tide was about the end of flood, within an hour of high water.

On 16th November 1886, the Beacon was passed at 13^h20 going up the loch with tide $4\frac{1}{2}$ hours flood; the temperature ranged from $49^\circ{\cdot}8$ to $49^\circ{\cdot}4$, reaching that minimum at the Beacon, and then rising to $49^\circ{\cdot}5$ and $49^\circ{\cdot}6$. The effect was almost too slight to be relied upon; but on the following day (see Section V., Plate XII.) it was visible to precisely the same extent.

* *Journ. Scot. Met. Soc.*, vol. viii., No. 4, pp. 108–110.

Observations off Gortans Point.—This station is fixed by Loch Gair entrance bearing N.W. by N. 9 cables. The depth is 35 fathoms (Section 18, I., Pl. 9 in Part I.) in the centre of the shallow and uniform Gortans Basin, which serves as a sort of trap between the Upper Basin of Loch Fyne and the Arran Basin.

The density of the water is as follows :—

	Surface, 9 observations.		Bottom, 9 observations.
Mean, ...	1·02398	...	1·02467
Maximum, . . .	1·02452	...	1·02493
Minimum, . . .	1·02224	...	1·02403
Average percentage of pure sea-water,	92·7		94·9

In vertical section 94·5, or in normal year 94·2.

TABLE XXV.—*Temperature Observations off Gortans Point.*

No.	1	2	3	4	5	6	7	8	9	10	11
Date	19.4.86	21.6.86	22.6.86	11.8.86	28.9.86	16.11.86	29.12.86	5.2.87	29.3.87	10.5.87	15.6.87
No. of Points .	7	3	11	7	7	8	6	6	12	6	9
Temp.	42·2	45·8 ?	44·9	49·8	51·6	50·1	46·4	44·3	44·1	45·8	47·9
Slope	+1·0	+3·6	+2·7	+2·9	+1·6	−1·3	−1·3	−0·5	+0·4	+0·9	+2·8

No.	12	13	14	15	16	17	18	19	20	21	22
Date	7.7.87	15.8.87	16.8.87	23.9.87	16.12.87	3.1.88	7.1.88	14.2.88	22.3.88	4.6.88	16.10.88
No. of Points .	9	12	7	6	6	6	6	6	6	6	6
Temp.	49·5	51·2	51·6	53·1	47·3	46·0	46·1	44·9	42·9	45·7	49·9
Slope	+4·2	+3·7	+3·4	+1·7	−0·8	−0·4	+0·3	0·0	0·0	+1·6	−0·1

As a rule, the temperature at Gortans was more extreme than at Furnace on the slope of the Upper Basin, being higher in the warming months, lower in the cooling.

The small slope of the curves is remarkable, the greatest positive value being 4°·2, the greatest negative value, 1°·3. The range is almost entirely confined to the upper 10 fathoms, and often to the upper 5 fathoms, the lower 25 fathoms being usually either homothermic or of very gentle and uniform slope. In fact, the general character of the curve resembles that of the Arran Basin rather than that of barred lochs. The size of the entrance and exit to the Gortans Basin relatively to its depth, taken together with the strong tides which traverse it and the vertical mixing at the Otter Bar, are quite sufficient to account for this effect. In discussing the temperature sections it will be shown that the Gortans Basin plays quite a distinct part in the seasonal temperature changes.

Curve 3 is interesting, taken in connection with the fragment of Curve 2 (see fig. 27, Plate XXVIII.), showing a mixing and cooling of the upper 5 fathoms, while the rest of

the curve is practically unchanged. On the 21st June 1886 (Curve 2) the wind was light from the north, tide half hour ebb ; on the 22nd (Curve 3) squally from the south, and the tide was about half flood. These different conditions seem sufficiently to explain the change.

Curves 13 and 14 (August 15th and 16th, 1887) are interesting in being, so far as the defective data of Curve 14 can show, precisely alike, with one small exception. This is a break in the uniform paraboloid by 3 fathoms of straight line, just above 20 fathoms in No. 13, just below it in No. 14. Curve 12 is reproduced as one of the most perfect specimens of a positive paraboloid.

Curves 17 and 18, for January 3rd and 7th, 1888, have almost the same mean temperature (46° and 46°·07). The former is above 46° below 10 fathoms, and below 46° above that depth, while in the latter this relation is inverted. But since the extreme temperatures in No. 17 are 45°·8 and 46°·2, and those in No. 18 are 46°·4 and 45°·9, there is scarcely room for detailed comparison.

The homothermic change of the lower layers in this basin, where there is an exceptionally complete system of interchange of water, strongly confirms the explanation of the *modus operandi* of this form of change, arrived at from the study of the Arran Basin.

Observations at Minard and Paddy Rock.—At Minard, Loch Fyne is constricted, and the surface divided into several channels by a group of islands. The two chief channels in which observations were sometimes made are "Minard" on the western shore, with a maximum depth on the sill of 12 fathoms, and "Paddy Rock" on the eastern shore, which is somewhat wider, and has a maximum depth of 18 fathoms. These channels separate the deep Upper Basin of Loch Fyne from the Gortans Basin.

The density of water may be assumed as the mean of that at Gortans and Furnace.

TABLE XXVI.—*Temperature Observations at Minard and Paddy Rock.*

No.	1	2	2 (*a*)	3	4	5	6	7	8	9*	10
Date	5.2.87	29.3.87	29.3.87	10.5.87	15.6.87	7.7.87	15.8.87	23.9.87	6.1.88	6.1.88	16.10.88
No. of Points	3	6	6	4	4	6	8	3	6	9	4
Temp.	44·3	44·1	44·2	45·5	49·6	51·8	52·2	52·9	46·4	46·5	49·9
Slope	−0·8	+0·4	+0·2	+0·6	+2·3	+5·7	+3·0	+0·8	−0·1	+0·4	0·0
Place†	M	P	M	M	P	P	P	P	P	M–P	P

* Deep water. † M = Minard Channel. P = Paddy Rock Channel.

These curves show no notable peculiarities, except that the change of temperature is mainly confined to the superficial 5 fathoms. The great range of No. 5 is remarkable : surface temperature 60°·4, at 4 fathoms 50°·6, and at bottom (15 fathoms) 49°·2.

Observations at Furnace.—The position where observations were made is defined

by the bearing Fairy Hill S.E. ½ E. 2½ miles, which is in mid-channel opposite Furnace Quarry, and the depth is 35 fathoms. This point is on the threshold of the Upper Basin of Loch Fyne, which deepens abruptly to the east, while to the west there is a stretch of 3 miles, averaging 35 fathoms in depth along the axis, with very slight irregularity, then rising to form the Minard bar.

The density of the water was found to be as follows :—

	Surface, 9 observations.		Bottom, 9 observations.
Mean, ...	1·02380	...	1·02463
Maximum, ...	1·02452	...	1·02488
Minimum, ...	1·02134	...	1·02421
Average percentage of pure sea-water,	91·0	...	94·7

In vertical section 94·1, or in normal year 93·8.

TABLE XXVII.—*Temperature Observations at Furnace.*

No.	1	2	3	4	5	6	7	8	9	10
Date	19.4.86	22.6.86	11.8.86	27.9.86	16.11.86	29.12.86	5.2.87	29.3.87	10.5.87	15.6.87
No. of Points	7	7	15	10	8	6	6	9	6	12
Temp.	42·2	44·2	47·8	49·3	49·7	47·0	44·6	44·2	45·0	48·2
Slope	+0·8	+2·1	+8·1	+6·5	+0·2	−1·4	−2·3	+0·5	+0·8	+4·5
Actual Slope	...	+2·9 −0·8	...	...	−0·6 +0·8	−1·8 +0·4	...	...	...	...

No.	11	12	13	14	15	16	17	18	19	20
Date	8.7.87	15.8.87	23.9.87	16.12.87	3.1.88	6.1.88	14.2.88	22.3.88	25.8.88	16.10.88
No. of Points	14	11	9	9	6	6	9	6	12	6
Temp.	49·9	50·9	52·2	47·9	47·3	47·1	45·6	43·2	50·1	49·5
Slope	+8·8	+7·0	+3·9	−2·0	−0·3	−0·4	−1·5	−0·7	+7·5	+1·0
Actual Slope	...	...	...	...	...	−0·6 +0·2	−2·5 +1·0	...	...	...

The observations at Furnace show on the whole less range than those at Dunderawe, both places occupying similar positions at either end of the Upper Basin, and the depths being equal. The mean temperatures were somewhat higher in winter and somewhat lower in summer at Furnace. This greater uniformity is well shown in Curve 9 (May 1887) of each set (compare fig. 28, Plate XXVIII., and fig. 36, Plate XXIX.). For Furnace the curve is a straight line of mean 45°·0 reduced range + 0°·8, and for Dunderawe it has mean 45°·8 and reduced range + 5°·2.

At Furnace there is a marked tendency towards S-shaped curves, more distinct than those seen in the Gareloch, and showing a tendency, as in No. 10 (fig. 28), to pass into

the contorted form. This is brought about in many cases by a very steep gradient at the bottom of the curves, such as is rarely shown elsewhere. Curve 10, for example, shows a fall of 1°·4 in the last 3 fathoms, where the gradient is almost as steep as in the surface layers, and far steeper than at any intermediate point. Curve 11 also shows a marked steepening of the gradient, a concave parabola below 20 fathoms.

In No. 12, the steepest gradient in the whole curve lies between 28 and 30 fathoms; but Curve 13 (fig. 28), shows this peculiarity most strikingly. In this curve (23rd September 1887) there is from the surface to 5 fathoms a fall of 1°·6, from 5 to 32 fathoms a net fall of 1°·1, while from 32 to 34 fathoms the fall is as great as 3°·8 in only 2 fathoms. This peculiarity, only noticeable between June and September 1887, and comparison of the sections of the loch, shows a narrowing of the zone of rapid change of temperature towards the S.W. end of the basin, the layer of rapid change of temperature being usually much less clearly marked. The upper layers of water are seen by the section to be more fully mixed or less affected by land at the Furnace end of the Basin at all times of the year.

There was only one case of short-interval observations, Nos. 15 and 16, on January 3rd and 6th, 1888. The mean temperature fell from 47°·3 to 47°·1, or at the rate of 0°·7 per day. The fall was 0°·4 in the top 5 fathoms, 0°·3 in the bottom 5 fathoms, and, except for an irregular rise between 5 fathoms and 15 fathoms, was fairly uniform for the rest (fig. 28, Plate XXVIII.).

The observations at this station are most valuable, as showing the effect of the sudden steepness of descent of the loch's bed on the physical condition of the water.

Observations off Strachur and Inveraray.—It is convenient to consider the two deepest stations at which observations were made in the Upper Basin of Loch Fyne together. The station about midway between Strachur and Kenmore was in the centre of the Basin, and practically at its deepest part, although patches of equal depth occur between it and Furnace. The depth is 75 fathoms, being 15 fathoms deeper than the observing point between Inveraray and St Catherines. The latter may be looked on as in the deepest water of the Basin also, as the slope along the axis is very uniform. While the deepest water off Strachur lies nearly in the middle of the loch, that off Inveraray is very much nearer the south-eastern than the north-western shore. This is partly because of the widening of the loch by the large bay known as Loch Shira, and partly because of the shallowing of the north-western margin by the deposits brought down by the rivers Aray and Shira.

The following summaries of the conditions at the two points show that the water at Inveraray is of slightly lower salinity throughout than at Strachur. The difference at the bottom is very slight, that at the surface considerably greater on account of the inflowing rivers.

At the Strachur station the position of observation was Fairy Hill S.W. by S. $\frac{1}{2}$ S.

2 miles 8 cables, and the depth 75 fathoms. (Section 18 D, Plate 9, in Part I.) The density of the water was :—

	Surface, 12 observations.		Bottom, 12 observations.
Mean, ...	1·02246	...	1·02458
Maximum, ...	1·02446	...	1·02517
Minimum, ...	1·01197	...	1·02430
Average percentage of pure sea-water,	85·7	...	94·8

In vertical section 93·3, and in normal year 93·0.

For Inveraray the position was Inveraray Castle N.N.W. (on with Aray Bridge) 1 mile. Depth 60 fathoms. The density of the water was :—

	Surface, 12 observations.		Bottom, 10 observations.
Mean, ...	1·02130	...	1·02456
Maximum, ...	1·02439	...	1·02487
Minimum, ...	1·01311	...	1·02404
Average percentage of pure sea-water,	83·2	...	94·6

In vertical section 92·7, or in normal year 92·3.

TABLE XXVIII.—*Temperature Observations off Strachur.*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	19.4.86	20.4.86	21.6.86	11.8.86	25.8.86	27.9.86	17.11.86	29.12.86	4.2.87	29.3.87	10.5.87	15.6.87	8.7.87	15.8.87
No. of Points	7	7	12	21	10	13	18	9	10	17	15	15	14	13
Temp.	42·1	42·1	44·2	45·6	46·2	47·2	47·5	46·2	45·4	44·6	45·0	46·4	46·8	47·9
Slope	+0·4	+0·6	+4·6	+8·0	+9·2	+8·3	+4·0	−1·3	−2·6	−1·0	+3·1	+5·8	+8·3	+9·6
Actual Slope	...	...	+6.2	+8·7	+9·3	...	−1·5	−3·9	−3·0	...	+3·6	...	...	...
	...	...	−1·6	−0·7	−0·1	...	+5·5	+2·6	+0·4	...	−0·5	...	...	...

No.	15	16	17	18	19	20	21	22	23	24	25	26	27	...
Date	23.9.87	5.11.87	7.11.87	17.12.87	14.2.88	28.2.88	22.3.88	7.4.88	4.6.88	18.7.88	25.8.88	16.10.88	18.10.88	...
No. of Points	12	12	9	15	18	9	9	9	9	15	12	12	15	...
Temp.	48·9	48·3	48·4	47·5	45·6	44·5	43·8	43·1	44·3	45·3	46·9	46·8	47·0	...
Slope	+8·1	+2·1	+4·1	−1·2	−1·1	+0·2	−0·8	+0·8	+3·0	+4·4	+11·2	+5·7	+5·6	...
Actual Slope	...	−2·3	−0·1	−3·3	−2·6	...	...	...	...	...	...	−0·2	−0·2	...
	...	+4·4	+4·2	+2·1	+1·5	...	...	...	...	...	...	+5·9	+5·8	...

TABLE XXIX.—*Temperature Observations off Inveraray.*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	19.4.86	21.6.86	10.8.86	24.8.86	16.9.86	17.9.86	27.9.86	17.11.86	30.12.86	5.2.87	29.3.87	10.5.87	16.6.87	8.7.87
No. of Points	7	15	19	7	4	11	12	15	12	10	17	12	16	18
Temp.	41·7	43·6	45·7	46·4	47·7?	47·6	47·7	48·3	46·8	45·3	44·6	45·0	46·6	47·1
Slope	+0·7	+2·8	+9·5	+10·8	+10·2	+9·3	+8·4	+2·5	−1·0	−2·7	−0·5	+4·1	+7·3	+10·3
Actual Slope	...	+4·7	+10·4	+11·1	...	...	...	−2·0	−2·6	−3·2	...	+4·6	...	...
	...	−1·9	−0·9	−0·3	...	...	...	+4·5	+1·6	+0·5	...	−0·5	...	...

No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Date	16.8.87	23.9.87	13.10.87	5.11.87	17.12.87	14.2.88	23.3.88	4.6.88	25.8.88	27.8.88	1.9.88	17.10.88	26.8.89	3.9.89
No. of Points	15	10	9	12	16	15	9	9	15	12	6	12	13	13
Temp.	48·4	49·1	49·0	49·1	47·5	45·7	43·6	44·3	47·5	47·7	49·7?	47·0	48·1	48·6
Slope	+9·9	+7·3	+5·0	+1·3	−2·8	−1·1	−0·8	+2·6	+12·1	+12·1	+10?	+5·5	+8·4	+6·6
Actual Slope	...	...	...	−2·0	−3·9	−2·6	...	...	...	...	...	...	...	...
	...	...	...	+3·3	+1·1	+1·5	...	...	...	...	...	...	...	...

Out of the twenty-one occasions when observations were made at both stations, there was no difference in the mean temperatures of vertical soundings five times, the temperature at Strachur was higher five times (0°·9 as a maximum), and that at Inveraray was higher eleven times (0°·8 as a maximum). On the whole, the mean temperature of the water at Inveraray was 0°·1 higher than at Strachur. As a rule, the temperature at Inveraray was higher in the warmest months, and approached equality or became colder than at Strachur during the cold months. The slope of the curves was always the same at both stations, but the amount of slope was on the whole 0°·07 greater for Inveraray than for Strachur. On two occasions the slope had the same value, nine times it was greater at Strachur (maximum difference 1°·8), and ten times it was greater at Inveraray (maximum difference 2°·0). The slope was greater at Inveraray than at Strachur only during the warming months—from May to September; during the cooling months it was greater at Strachur, surface heating being stronger at the former, surface cooling at the latter place.

Change of Temperature in short intervals of time.—There are five cases of observations at the same point within two days, three of these being at Strachur and two at Inveraray.

Observations on 19th and 20th April 1886 at Strachur, Nos. 1 and 2 of Table XXVIII. —The two observations gave identical results below 10 fathoms, the water being practically homothermic at 41°·9; and the upper 5 fathoms were at 42°·2 on the first occasion, and 42°·5 on the second (fig. 29, Plate XXVIII.). The narrowness of Loch Fyne and the numerous disturbing causes, such as wind, rivers, and rainfall, make it hopeless to attempt to measure the effect of radiation in the way suggested for the Skate Island observations.

Observations on 5th and 7th November 1887 at Strachur, Nos. 16 and 17 (see fig. 30, Plate XXVIII.).—The mean temperature was higher by 0°·1 on the second occasion, but

this result may be due to the fact that No. 16 was fixed by 12 points, No. 17 by only 9. No. 16 showed a rapid rise from 45°·9 on the surface to 50°·0 at 10 fathoms, a fall increasing more rapidly as it deepened to 47° at 53 fathoms, and then a gradual fall to 45°·5 at the bottom. No. 17 was practically constant at 49°·8 from surface to 25 fathoms, a possible maximum of 49°·9 being shown at 20 fathoms. Below this depth the curves practically coincided. The upper 25 fathoms of No. 16 gave an irregular parabola with mean temperature 49°·5; this is straightened in No. 17 into a vertical line with mean temperature 49°·8; the disturbance practically does not extend below 25 fathoms, and shows a definite warming as well as mixing in the upper layers. The 5th was calm, while on the 7th a strong north-easterly wind blew down the loch. The curves of the same date for Cuill and Dunderawe may be compared with those for Strachur, and the relation between these is well brought out in Sections XIV. and XV., Plate XIV.

Observations on 16th and 18th October 1888, curves 26 and 27 (fig. 31, Plate XXVIII.).—These show a rise of 0°·2 in two days. The curves were very fully traced out, and are remarkably irregular. The upper part of both for 10 fathoms shows mean temperature of about 49°·8, nearly uniform, then a uniform convex parabola descending to 44°·1 at 50 fathoms in No. 26, and a concave parabola, joined at 25 fathoms by 5 fathoms of uniform temperature to a regular convex parabola descending to 44°·2 at 50 fathoms in No. 27. This shows two areas of considerable warming about 20 fathoms and 35 fathoms. On the 16th the observation was made at 15^h45 in a calm: the temperature of the air was 51°·3, and during the earlier part of the day there had been a very light air from the south-west. October 17th was calm, overcast, and a little cooler, while on the 18th the observation was made at 12^h30, with the air temperature at 51°·2, the weather misty, and a freshening breeze blowing from the south-east. There is nothing in the record of weather to account for the remarkable heating at 30 fathoms; and were it not that the temperature recorded at 35 fathoms points in the same direction, one would be tempted to look on that at 30 as a misreading of one degree.

Observations on 16th and 17th September 1886 at Inveraray, Nos. 5 and 6 in Table XXIX. (fig. 32, Plate XXVIII.).—The data for curve No. 5 are too incomplete to allow of comparison with No. 6, but those of No. 7 for 27th September (see fig. 33) are exceptionally complete. Below 50 fathoms the three curves are very much alike, the temperature being close to 44°. In the ten days elapsing between Nos. 6 and 7 the surface layer showed slight cooling, and the intermediate layers slight warming, but the total change of temperature was only a rise of 0°·1. These two are the most perfect examples found of S-shaped curves, *i.e.*, compound heterothermicity without intermediate maxima or minima. They are compounded of two parabolas, the upper concave, the lower convex to the origin. The limiting form of such a curve would represent the superposition of a mass of uniformly hot water upon a mass of uniformly cold water. The maximum change of temperature with depth took place about 25 or 30 fathoms, where a fall of 3°·4 took place in 5 fathoms.

Observations on 25th and 27th August 1888, Nos. 23 and 24 (fig. 34, Plate XXIX.)

at Inveraray.—These are the curves of greatest slope (12°·1) observed in Loch Fyne, and represent the maximum heating effect. They are the nearest approaches to simple positive paraboloids, and bear every evidence of being due to surface heat being propagated uniformly downward. Omitting the superficial fathom, which showed some cooling on the 27th, the upper layer of water showed well-marked heating down to 25 fathoms, and below that depth a possible slight cooling, although the temperature was probably the same on both occasions in the lower half. On the whole, the result of the interval of two days was a rise of 0°·2 in temperature. The 25th was a bright, warm day (air-temperature 62°·7 at time of observation, 10^h0), with a light, southerly breeze. The weather on the 27th was similar, though the air was cooler (57°·0 at the time of observation, 17^h20), and the breeze rather stronger. The gain of temperature for the first 20 fathoms may be put down as 0°·5; and as there were 36 hours of daylight and 19½ hours of darkness between the observations, on the hypothesis of equal rates of gain and loss of heat (see p. 58), the effect of solar radiation and contact with warm air was to raise the temperature at the rate of 0°·03 per hour to the depth of 20 fathoms, or 0°·012 per hour for the whole depth. These are much smaller values than were obtained in similar cases of double observations at a short interval of time at Skate Island, and equally valueless. Observations at Inveraray were made by me from a rowing boat on 26th August and 3rd September 1889, Nos. 27 and 28 (fig. 35, Plate XXIX.). August 26th was calm, with overcast sky, and air-temperature 56° when the observation was taken at 11^h30. The tide was about high-water. In the afternoon the weather became squally. The intervening week was warm, with light breezes and little rain, except on the 2nd September, when a strong easterly breeze was blowing. On the 3rd the sky was overcast, the weather calm and hazy, with a very light air from the south-east, and the tide at the time of observation was within an hour of low-water. The result of the week's warm weather was a rise in the mean temperature of the sounding from 48°·1 to 48°·6. The two curves crossed at 10 fathoms, the upper layer having cooled about 0°·7 on the average, while the 50 fathoms beneath had been warmed up almost uniformly by 0°·4. This plainly points to a considerable mixing of the water in the interval, either by wind or tide, or both. No salinity observations were made. On the first occasion the temperature gradient was exceptionally uniform from surface to bottom, the curve being between a straight line and a simple paraboloid; but on the second occasion the gradient of the first 20 fathoms had been greatly reduced (clear evidence of mixing), that of the lower 30 fathoms was unchanged, and the intermediate 10-fathom zone showed a marked accentuation, the curve having become a compound of two paraboloids.

Cross Section at Inveraray.—A cross section of Loch Fyne at Inveraray, from the usual observing station to Inveraray pier, was made in the autumn of 1889 on two occasions, August 26th and September 3rd. The isotherms were practically parallel and horizontal in both cases, although in the interval there had been strong winds. Both the days of observation were calm.

Seasonal Variations.—The seasonal variations of vertical temperature in the deepest

water of Loch Fyne may be traced by means of the curves, as at Skate Island. Instead of taking the Inveraray or Strachur observations alone, the two are combined, with the effect of considerably smoothing the curves (see figs. 16 to 18 on Plate VII.). The dates are selected to correspond with those at Skate Island; the references to the curves are given in Table XXX. The numbers correspond with those for Skate Island (Table XX.).

TABLE XXX.—*Typical Vertical Temperature Curves in Loch Fyne.*

Curve.	1886–87.				1887–88.				1888.			
	Reference Table		Date (Mean).	Time Interval Days.	Reference Table		Date (Mean).	Time Interval Days.	Reference Table		Date (Mean).	Time Interval Days.
	XXVIII.	XXIX.			XXVIII.	XXIX.			XXVIII.	XXIX.		
I	1–2	1	April 19	...	10	11	March 29	53	21–22	21	March 28	42
II	3	2	June 21	63	11	12	May 10	42	23	22	June 4	68
III	4	3	Aug. 11	51	12–13	13–14	June 26	47	25	23–24	Aug. 26	83
IV	6	6–7	Sept. 25	45	15	16	Sept. 23	89	...	...	...	...
V	7	8	Nov. 17	53	16	18	Nov. 11	49	26–27	26	Oct. 17	52
VI	8	9	Dec. 29	42	18	19	Dec. 17	36	...	...	...	...
VII	9	10	Feb. 4	37	19	20	Feb. 14	59	...	...	...	...

While the form of the curves is different in detail for each year, there is sufficient similarity between them to suggest that the year 1886–87 may be taken as a type. The only difficulty which this year presents is the low temperature and perfect homothermicity of its minimal curve. If that could be set aside, the difference in range varies in a very interesting way with depth. At the surface the seasonal amplitude may be as much as 20°, at 10 fathoms it is only 10°, at 35 fathoms 5°, and at 70 fathoms only 2°. Plotting these values, and extending the curve to the depth of 105 fathoms, the annual range would come out as only 1°, and at 150 fathoms it would practically vanish. The contrast of this condition with that at Skate Island is striking. There it would appear that the range of seasonal temperature at the bottom is scarcely less than that at the surface, and its value may be taken as at least 10°. The *régime* of the deep water as regards temperature is thus entirely different in the two basins. The physical differences are that Loch Fyne is smaller, shallower, more completely invested by high land, more completely barred off from the open sea, and with a greater difference between the density of surface and bottom water than is the case in the Arran Basin. The most striking difference in the curves is the absence of homothermic change of temperature in Loch Fyne except in very rare cases. Considering homo-

thermic change of temperature in deep water as a sign of free mixture of the water, we are justified in accepting the curious form of the Loch Fyne curves as evidence of the normally restricted circulation in the deep water of that basin. The homothermic agencies being restricted, fuller play is given to the influence of radiation and the contact of warm air or warm water in producing temperature changes. The curves appear to be in large measure conduction curves, convection being reduced to a minimum. The average difference between the density of surface and bottom water at Strachur was 0·00212, and at Inveraray 0·00326, compared with 0·00052 at Skate Island. No fall of temperature would be sufficient to invert the density gradient due to salinity, and thus the conditions in Loch Fyne resemble a vessel of water the temperature of which depends on a layer of oil floating on the surface. This question will be discussed more fully when speaking of the temperature sections of Loch Fyne.

The characteristic feature of these curves is their tendency to assume a sickle shape. How this form is derived from the homothermic will be explained when dealing with the sections, and, for the present, we may start with Curve 2, which in 1886 showed a much more pronounced intermediate minimum than in 1887. Above 15 fathoms this curve shows rapid heating in progress from the surface downward. Curve 3, after the lapse of 51 days in 1886, 47 in 1887, and 83 in 1888, shows no change of temperature at the bottom, nor in 1886 within 15 fathoms of the bottom, but an increasing rise of temperature as the surface is approached, the curve assuming the form of a paraboloid, significant of the most rapid stage of surface-heating. No. 4, after 45 days in 1886, and 89 days in 1887, shows an approximation to the S-shape. In 1886 this curve almost exactly conforms to the "oceanic" type. The lower part is a parabola showing the continued descent of heat, but the bottom fifteen fathoms remain unchanged in temperature. Surface-cooling having set in, the upper layers, losing heat in both directions, have given to the upper part of the curve the form of an inverted parabola. A zone of rapid change of temperature occurs between 25 and 30 fathoms. In No. 4 for 1887 later heating seems to have turned the inverted parabola into a direct one again. Curve 5 is a very fine example of the negative sickle shape, produced by the rapid loss of heat from the surface, and the more gradual transference of heat downwards, although the bottom temperature was not yet raised. Curve 6 is of similar form, but displaced in a negative direction, except at the bottom, where the temperature now begins to rise. In 1886 there was a zone of very rapid change of temperature between 45 and 50 fathoms. The progress of surface-cooling has now made the temperature of the upper layers colder than the remains of the previous cold at the bottom. Curve 7 in 1886 is an approximation to a negative parabola, the bottom water having practically reached its maximum while the surface is at the annual minimum. In 1887 there had been rapid and almost homothermic cooling to the bottom. The transition of Curve 7 to 1 of the following year was in both cases brought about by nearly homothermic cooling.

It is very interesting to notice that, starting in June 1886 at 44°·2, the bottom water required 149 days before any change of temperature occurred; 79 days more raised the

temperature (*i.e.* 228 days of heating) to 46°·0; and only 53 days were necessary to carry it back to 45°·2. In 1887, starting from 44°·7 in May, 221 days brought the bottom temperature to 46°·2, and 101 days more brought it back to 43°·8.

Thus the rise of temperature at the bottom was at the average rate of 0°·008 per day in 1886 and 0°·007 in 1887; while the fall of temperature took place at the average rate of 0°·015 per day in 1886 and 0°·023 in 1887. The average rate of cooling at the bottom for the two years under consideration appears to be two and a half times as rapid as the average rate of heating; in other words, the heat gained in five days is lost in two.

The seasonal changes of temperature at Strachur are represented diagrammatically by the time-depth figure (fig. 8, Plate V.), which is on the same scale as that for Skate Island, with which it may profitably be compared.

The most striking contrast between the two is the strongly-marked diagonal run of the isotherms in the Strachur diagram, and the fact that the penetration of heat was greatest in 1887, while for Skate Island it was greatest in 1886. The retardation of the date of maximum temperature as the depth increases is beautifully brought out.

In 1886 the surface was above 50° from July 1st to October 15th, and the isotherm of 50° only reached its maximum depth (23 fathoms) on October 1st. It thus took 92 days to carry this isotherm 23 fathoms down, while at Skate Island 110 days sufficed to carry it to 105 fathoms.

In 1887 the surface was above 50° from May 24th to November 1st, and the temperature of 50° penetrated to its greatest depth (30 fathoms) on September 24th, thus requiring 123 days to work down, while 37 days sufficed for its return to the surface. At Skate Island practically the same time was taken for the temperature of 50° to reach 64 fathoms, which was the maximum attained; and early in August the temperature of 54° worked down at both stations to the same small depth of 8 fathoms.

In 1888 the observations are complete enough to show that the surface was over 50° from July 24th to October 18th, while the maximum depth, reached by that temperature on August 24th, after 31 days, was $12\frac{1}{2}$ fathoms.

The maximum temperature at the bottom, due to the summer's heat of 1886, was reached on February 24th, 1887, 194 days after the date of the surface maximum, and 54 days after the succeeding surface minimum. The minimum at the bottom occurred on April 15th, 50 days after the maximum. The summer's heat of the exceptional year 1887 reached the bottom more rapidly, the maximum occurring there on December 31st, just 169 days after the surface maximum, and 45 days before the surface minimum. The minimum at the bottom was on April 24th 114 days later than the maximum.

In the Channel the bottom and surface maxima are simultaneous, in the Arran Basin at Skate Island the average of two years showed the bottom maximum to be retarded 63 days, while in Loch Fyne, at Strachur, the retardation averaged 182 days, or practically six months. This is a very striking illustration of the influence of increasing

isolation on thermal conditions, and shows how much the ready change of temperature in natural bodies of water depends on free circulation.

Observations at Dunderawe.—At the observing station, Dunderawe Castle bore N. 2½ cables, soundings being made in the centre of the loch at a depth of 35 fathoms. This was on the slope towards the head of the loch, about midway between the head and the relatively flat floor of the deepest part, the slope being much more gradual than that near Furnace at the other end. The observed density of the water was as follows :—

	Surface, 9 observations.		Bottom, 9 observations.
Mean, ...	1·01914	...	1·02450
Maximum, ...	1·02440	...	1·02479
Minimum, ...	1·00657	...	1·02412
Average percentage of sea-water, . .	70·1	...	94·2

In vertical section 90·2, or in normal year 89·8.

TABLE XXXI.—*Temperature Observations at Dunderawe.*

No.	1	2	3	4	5	6*	7	8	9	10	11
Date	20.4.86	22.6.86	11.8.86	27.9.86	17.11.86	30.12.86	5.2.87	29.3.87	10.5.87	16.6.87	8.7.87
No. of Points .	9	9	10	7	12	15	6	13	9	14	12
Temp. . . .	41·8	44·5	47·9	50·0	49·0	47·0	44·5	45·0	45·8	47·3	47·9
Slope	+0·3	+5·1	+9·7	+7·3	−1·9	−4·0	−2·6	−0·9	+5·2	+6·1	+8·2

No.	12	13	14	15	16	17	18	19	20	21	22
Date	15.8.87	23.9.87	5.11.87	7.11.87	17.12.87	14.2.88	23.3.88	2.6.88	24·8·88	25.8.88	17.10.88
No. of Points .	9	8	10	12	15	12	6	9	13	10	6
Temp. . . .	50·1	51·1	49·8	49·6	47·0	45·9	43·2	45·3	49·2	49·3	49·0
Slope	+8·0	+4·8	−1·1	+0·6	−4·7	−2·1	−0·4	+2·4	+9·7	+10·1	+2·3

* West of Dunderawe.

Curves of very slight slope, showing almost homothermic conditions, occurred three times—Nos, 1, 15, and 18. No. 15 will be specially alluded to, the others were both early spring curves at or near the minimum temperature of the year.

Curves of great range are represented by ten positive and five negative cases, most of which are somewhat irregular. Cases of well marked intermediate minimum in the positive curves occurred in No. 2 (June 1886), and of intermediate maximum in a negative curve in No. 5 (November 1886) and No. 17 (February 1888), the latter being a very well formed sickle shape.

The main feature of the Dunderawe curves, like those for Inveraray and Strachur, is their great diversity of detail, showing compounds of the clearly recognisable types.

The steepest gradients were 2°·8 and 2°·6 in successive single fathoms from 0 to 2

(No. 10); 9° in 1 fathom from 1 fathom to 2 fathoms (No. 11),—in this case the range of the fathom above and the fathom below were only 0°·4 each; 8°·2 in 1 fathom (0–1 of No. 6), but here there was a change of 5° in 4 inches, the surface of the loch being frozen at the time, and the weather dead calm. Under the ice, at 2 inches depth, the temperature was 36°, and at 6 inches 41°, at 6 feet 44°. The other cases are 2°·7 in 1 fathom from 1 to 2 fathoms (No. 14); 8°·8 in 4 fathoms, or an average of 2°·2 per fathom in No. 21. All these are cases of rapid surface heating or cooling.

An interesting case of possible erroneous deduction is shown in looking at the mean temperatures of the lowest 5 fathoms :—

Nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	21
Temperature	41·6	42·9	44·2	45·2	48·7	47·2	45·6	45·2	44·3	45·2	45·7	46·8	48·5	49·4	49·2	48·2	45·6	43·4	44·0	44·7	45·9	47·7
Date				27.9.86	17.11.86	30.12.86	5.2.87	29.3.87	10.5.87	16.6.87	8.7.87											

Here observations on Sept. 27th, 1886, March 29th and June 16th, 1887, gave exactly the same result; and if no other observations had been taken it might reasonably be supposed that at the depth of 35 fathoms the temperature was constant, whereas these figures happened to be observed in course of successive stages of heating up, cooling down, and heating up again. Here the apparently impartial distribution of dates—autumn, spring, summer—would be apt to confirm a rash generalisation. The existence of constant temperature at the bottom in the case of Inveraray and Strachur would have been accepted as proved if three observations in 1886 and two in 1887 had been omitted. Frequent cases of such fallacy by coincidence have impressed on me the great caution necessary in uniting points by a curve.

On November 5th and 7th, 1887, observations were made, on the former day in calm weather, on the latter day with a strong N.E. (down-loch) wind. Both were in the afternoon, when the tide was about the same phase. On November 5th the mean vertical temperature was 49°·8, on the 7th 49°·6. On the 5th (Curve 14) there was low surface temperature (45°·9), rising to 49°·8 at 5 fathoms, stationary at or above 50° from 7 fathoms to 24 fathoms, then sinking to 49°·2. On the 7th (Curve 15) the temperature nowhere reached 50°. It was 49°·8 on the surface, 49°·9 at 10 fathoms, and then fell steadily to 49°·2. This showed thorough mixture of the water by the action of wind. The sounding on the 7th was about 1 fathom deeper than on the 5th, and thus the mean temperature of the latter was slightly reduced. There was practically no loss or gain of heat between the two occasions, the difference being merely a redistribution of temperature by mixture. Curves 20 and 21 were observed on August 24th and 25th, 1888 (see fig. 37 in Plate XXIX.). Both days show great range of temperature. On the 24th it fell from 57°·1 on surface to 52°·9 at 5 fathoms; on the 25th from 60°·8 to 52°. On the 24th it fell gradually to 51°·8 at 12 fathoms, sharply to 48° at 22 fathoms, and with very exceptional abruptness to 45°·5 at 24 fathoms, then gradually to 44°·3 at the bottom. On the 25th the fall was slightly irregular, but in the main steady from 52° at 5 fathoms to 45°·8 at bottom. The curves crossed twice at 4 fathoms and 23 fathoms. On the second occasion there was marked

warming of the 4 superficial fathoms, cooling by nearly $\frac{3}{4}^{\circ}$ of the next 19 fathoms, and great warming of the lowest 10 fathoms. The mean temperature of the section was practically unchanged. The curves for both dates at Cuill were simply those of the upper 15 fathoms, the compensating action of the lower layers not there coming into play.

Curve 9 (fig. 36, Plate XXIX.), a simple parabola showing spring heating from the surface temporarily arrested, is interesting when compared with the nearly homothermic curve for Furnace (fig. 28, Plate XXVIII.) at the same date. The whole question thus requires for its explanation a study of the vertical axial sections, many of the peculiarities of temperature change being due to the upward surge of deep, cold water, caused by disturbance of equilibrium by down-loch winds. This action is quite different at Dunderawe and Furnace, the difference being due to the closed end of the loch lying beyond Dunderawe, so that up-loch winds produce a banking-up and return-under-current of surface water, while at Furnace the effect of a down-loch wind is to drive surface water away to the Gortans Basin.

Observations at Cuill.—This station, situated in mid-channel, near the head of Loch Fyne, has the farm-house of Cuill bearing N. by W. $1\frac{1}{2}$ cables. The depth is 15 fathoms. To the south-west the water deepens uniformly, to the north-east it shoals steadily, the station being on the upper part of the ascending slope at the head of the loch.

The density of the water, as observed, is as follows :—

	Surface, 10 observations.		Bottom, 9 observations.
Mean, . . .	1·01435	...	1·02427
Maximum, . . .	1·02420	...	1·02463
Minimum, . . .	1·00114	...	0·02359
Average percentage of sea-water,	56·8	...	93·4

In vertical section 87·3, or for normal year 86·8.

TABLE XXXII.—*Temperature Observations at Cuill.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11
Date . . .	20.4.86	22.6.86	11.8.86	27.9.86	17.11.86	5.2.87	29.3.87	10.5.87	16.6.87	8.7.87	15.8.87
No. of Points	7	9	12	4	9	9	5	9	9	8	7
Temp. . . .	41·7	46·2	51·1	52·3	48·7	44·0	44·4	47·8	49·5	48·7	53·1
Slope . . .	0·0	+5·1	+7·4	0·0	−2·7	−1·5	−0·6	+3·5	+3·9	+6·4	+4·9

No. . . .	12	13	14	15	16	17	18	19	20	21	...
Date . . .	23.9.87	5.11.87	7.11·87	17.12.87	23.3.88	2.6.88	24.8.88	25.8.88	27.8.88	17.10.88	...
No. of Points	4	6	11	12	6	3	9	6	8	6	...
Temp. . . .	53·1	49·4	49·6	44·7	43·2	45·6	52·8	52·1	53·7	49·5	...
Slope . . .	+2·5	−1·6	+0·1	−6·5	−0·1	+0·2	+4·3	+6·7	+7·2	+0·8	...

The curves, like those for shallow water in all parts of the Area, may be classed roughly into two groups,—the equinoctial occurring in spring and autumn, when homothermic conditions prevail, both being a straight line (the vernal occurring at the annual minimum, the autumnal somewhat after the annual maximum); and the solstitial, characterised by great slope, the summer (during the months of heating) being positive, the winter (during the months of cooling) being negative (see fig. 38, Plate XXIX.).

The homothermic curves for this station are Nos. 1 (April), 4 (September), 14 (November), 16 (February), 17 (June). No. 7 (March) very nearly conforms to the type. Of these No. 17 (June) is abnormal, occurring during rapid heating, and its homothermicity is due not to seasonal change, but to local and temporary mixture.

Of the summer solstitial curves, the form was paraboloid on two occasions,—No. 10, which showed a steady diminution of the rate of fall of temperature from surface to bottom, and No. 12, which was not sufficiently defined to speak certainly of. No. 9 was nearly of the same form, but differed by a rapid fall at the bottom. Nos. 18 and 19 also, except for flattening at the bottom, agree fairly with the type. No. 2 is a double parabolic curve, showing the division of the water into four zones, of rapid fall, nearly constant temperature, rapid fall, and nearly constant temperature. Nos. 8, 11, and 20 are paraboloid, except for a layer of constant temperature on the surface, in two cases showing surface cooling and an intermediate maximum. In these cases the most rapid change of temperature with depth took place well below the surface, but in all other cases the surface layer showed most rapid change. The steepest superficial gradients were 5°·6 in the first fathom, 7° in 2 fathoms (3°·5 per fathom) in No. 18 (24.8.88); 8°·6 in 3 fathoms (2°·9 per fathom) in No. 19 (25.8.88); 4°·2 in 1 fathom, or 8°·3 in 3 fathoms in No. 9 (16.6.87); 3°·2 in 1 fathom, or 11° in 3 fathoms (3°·7 per fathom) in No. 10 (8.7.87): 3° in 1 fathom (Nos. 3 and 20) is the maximum for those with a slight surface gradient.

The negative solstitial curves show the paraboloid form of a rapidly cooling surface layer resting on a uniformly warm mass in Nos. 7 and 13 (March and November respectively). No. 15 (December) shows a nearly uniform rise from surface to bottom with intermediate pauses, maximum gradient 4°·4 in 1 fathom (from 1 fathom to 2 fathoms). No. 5 is an interrupted paraboloid, showing fall of 6°·4 in 1 fathom (0 to 1 fathom), and 3°·4 in 1 fathom (from 2 to 3 fathoms). No. 6 (February) is remarkable as being the minimum for the season, and shows a range of 4°·4. This range is compounded of 3°·4 fall in the first 3 fathoms, and 1° fall in lowest 5 fathoms. The intermediate zone of 9 fathoms had constant temperature; as the whole mass might be expected to have at that season. Curves 13 and 14, observed on November 5th and 7th, 1887, are strikingly different. On the 5th it was calm, with average temperature 49°·5, surface at 46°, bottom at 50°·1; temperature of 49°·5 occurring at 4 fathoms. The 7th was a day of strong north-east wind, blowing directly down the loch; the mean temperature was 49°·6, the surface 49°·7, the bottom 49°·5, and the temperature

practically continuous between, a very striking case of complete mixture by wind without loss or gain of heat.

Curves 18, 19, 20 were observed on 24th, 25th, and 27th August 1888. The observations were all made in the afternoon, and in about the same state of tide. The wind was from a southerly quarter, very light on the 24th, fresh on the 25th, and strong on the 27th. It was practically an up-loch wind. On the 24th the mean temperature was 52°·7, on the following day 52°. The surface temperature had meanwhile risen from 60°·8 to 62°·3, the bottom temperature had fallen from 49°·4 to 47°·4. The depth was the same, 15 fathoms. The curves crossed at $2\frac{1}{2}$ fathoms, showing slight heating in the upper layers, and very marked and increasing cooling in the lower. The fall of 0°·7 in mean temperature was thus the result of great incursions of cold water from beneath, while warm surface-water was flowing in above. This serves to suggest a double action on the part of the south wind as shown (fig. 39, Plate XXIX), similar to the double action noted in the case of the Gareloch cross-section. Between the 25th and 27th, 1°·6 of warmth was added. All above 2 fathoms was greatly cooled, all below it still more greatly heated, the same temperature occurring about 3 fathoms deeper throughout than on the 25th. This might indicate that the continuance of the up-loch wind had overcome the double action, and was now driving the warmer water to the greater depths, and drawing up some cooler water to the surface. Figure 40, Plate XXIX, shows a possible explanation of this action. All above 1 fathom was cooler than on the 24th, so was all below 10 fathoms; but between 1 and 10 fathoms there had been a great rise of temperature. This matter will be treated more fully when considering the Temperature Sections.

Temperature Sections of Loch Fyne.—A series of vertical sections along the axis of Loch Fyne were drawn with the vertical scale exaggerated 150 times as compared with the horizontal, in order to enable the isotherms of every degree Fahrenheit to be conveniently represented. The section extends from Cuill to near Skate Island, in order to show the relation of Loch Fyne to the Arran Basin. From the 23 sections which have been drawn it is possible to obtain some insight into the thermal transactions of the water in Loch Fyne as a whole, and to calculate the mean temperature of the whole body of water at different times. They are reproduced in Plates XII. to XV.

Section I., 20th April 1886.—This shows the minimum and most uniformly distributed temperature of the entire series. Temperature varied but little from 42°, with a general seaward dip of isotherms; 42° occurred deeper at Inveraray and Strachur than anywhere else in the section. The prevailing wind at the time of observation was a fresh breeze down-loch. In all cases the surface was slightly warmer than the depths.

Section II., 21st–22nd June 1886.—The prevailing wind was on the whole westerly, or nearly up-loch, and light. The arrangement of temperature was remarkable. The surface was about or over 48° everywhere, except at Otter, where there was marked upwelling of colder water. The isotherm of 45° preserved an average position of about 10 fathoms, and the whole Gortans Basin was filled with water above 44°. The

isotherm of 44° is represented as touching the Minard barrier, although there was no observation to fix it, and it may not have come so far down-loch. The line of 44° ran up the section to Cuill at about 12 or 15 fathoms. The temperature at all stations fell steadily to about 20 fathoms where the minimum occurred (at Strachur 42°·3), thence the temperature rose much more slowly to the lower isotherm of 44°, which ran obliquely from near the lip of Minard Basin until it reached a depth of 50 fathoms at Inveraray. Beneath this was a gradual rise of temperature to 44°·1 or 44°·2. The upper layers were crowded with close parallel isotherms, showing surface heating. The lines of 44°, 43°, and 42°·5 formed a series of closed lenticular curves, near each other above and widely separated below, indicating a mass of isolated cool water entirely surrounded by warmer layers, and separated by the warmer Gortans Basin from water slightly below 44° at the same position (though without the intermediate minimum) in the Arran Basin.

Were it not for Section I. we would naturally assume that the isolated cold mass represented the winter minimum slowly working its way down through the remnants of the undisturbed warmth of the previous summer, and pursued above by the rapidly increasing warmth of the next summer. But Section I. shows that the whole mass had started at about 41°·8, and that considerable heating had taken place throughout. Hence the problem is to account for the water below 20 fathoms heating up more rapidly than that between 15 fathoms and 10 fathoms.

Many hypotheses were tested. The wind causing a rotary circulation either transversely or longitudinally might account for it, but there was no record of a prolonged steady wind likely to produce such a result, and when wind of the kind demanded by this hypothesis occurred, it was not accompanied by similar conditions in the water. No satisfactory conclusion as to the origin of the distribution of temperature has been arrived at.

The whole mass of water might be supposed to heat up gradually, most rapidly on the surface, until the mass from, say 15 fathoms downward, came to a temperature about 42°·5. Then tidal or wind action might be supposed to fill the Minard Basin with warm dense water at a temperature over 44°, and this crossing the Minard bar with the tide would, in consequence of its density, pour down the slope, warming the lower layers while the fresher upper stratum would be heated sufficiently to maintain it at a less density than the central cold area. This condition once established, would tend to persist. The density observations may be summarised as follows, the densities being given at the temperature of the water *in situ*.

[TABLE.

TABLE XXXIII.—*Density of Water* in situ *in Loch Fyne.*

		Cuill.	Dunderawe.	Inveraray.	Strachur.	Furnace.	Otter I.
April 1886	Surface . .	1·02600	1·02608	1·02576	1·02605	1·02585	1·02574
	Bottom . .	...	626	...	628	652	669
June 1886	Surface . .	478	560	562	559	580	627
	5 Fathoms .	564	...	600	579	...	643
	10 Fathoms .	594	...	...	...	...	...
	20 Fathoms .	...	618	...	...	...	...
	25 Fathoms .	...	...	636	...	...	...
	Bottom . .	623	618	638	636	649	665

The density of the water in Loch Fyne attained the actual maximum in June 1886, there being 2 per cent. more pure sea-water present than the average. However, April 1886 was also a month of exceptional salinity, the amount of sea-water present in Loch Fyne then being 1·3 per cent. above the average. In April the difference between the density *in situ* of surface and bottom water, expressed in units of the fifth decimal place, was 18 at Dunderawe, 23 at Strachur, 66 at Furnace, and 95 at Otter. These differences corresponded to an increasing difference in salinity between surface and bottom water as the Arran Basin was approached, due to the greater salinity of the bottom water seaward, the surface salinity on this occasion being nearly the same along the whole length of the loch. It is difficult to understand in the light of Table XXXIII. how density would account for the continuance of the cold layer of intermediate water, because at Inveraray the salinity (*i.e.*, density at 60° F.) of the water at 25 fathoms was 1·02465, and at the bottom 1·02486, a difference of 21, while the actual density *in situ* at 25 fathoms was in consequence of its low temperature, 1·02636, whilst that at the bottom was only 1·02638, and at the bottom at Strachur 1·02636, leading one to expect the formation of convection currents, or at any rate the rapid suppression of the intermediate minimum. The fact that a similar arrangement of temperature never occurred again, except to a very slight extent, which could be readily explained by local heating, points to some special circumstance in the Spring of 1886 as the cause. The surface salinity of the Loch Fyne stations was higher in June 1886 than on any subsequent occasion, and the same was true of Loch Strivanhead, while the Arran Basin was scarcely above its average, thus indicating the possibility of mixture with lower layers, and hinting at vertical circulation through wind action. But any argument drawn from this difference is weakened by the fact that in April 1886 the contrast in salinity between Loch Fyne and the Arran Basin was much greater, the surface water of the Basin being then actually fresher than that of the loch.

Section III., August 10th-11th, 1886.—The wind at the time of observation was light, and blew up the loch. Since June the Arran Basin had heated up to 53°·5 on the surface, and 45° on the bottom. The Minard Basin was filled with nearly uniformly warm water. The isotherms cross it nearly horizontally down to the level of the bars, but below that level the Gortans Basin remains warmer than the water at the same depth either outside or inside; *e.g.*, at 30 fathoms it is 48° in Arran Basin, 48°·3 in Gortans Basin, and 46° in the Upper Basin of Loch Fyne.

At Otter the warm skin is broken by somewhat superficial upwelling. In the Upper Basin below 45–50 fathoms the temperature is the same as in June. The cold mass is much reduced in size, and the area under 44° is now only 20 fathoms thick at Inveraray, its maximum. Its minimum temperature is 43°·3 (?), and the line of minimum has sunk to 35 fathoms. The cold mass is in contact with the landward end of the loch, but does not reach so far as Furnace. This cold sheet has effectually prevented the penetration of heat to the water below.

The upper isotherms below 10 fathoms show a strong down-loch dip, which is due, probably, not to shearing motion set up by wind, but to actual heating by the overflow of dense warm water from the Gortans Basin. That this is a very important factor is proved by density observations. From Furnace to Cuill, at about 5 fathoms, a number of isotherms run very close to each other, showing a thin layer of hot water resting abruptly upon the slowly warming, cooler layer below.

Section IV., 27th–28th September 1886.—The superficial layer of 20 fathoms ranges from 51° to 52°·5, the mass approaching to homothermic conditions, and entirely filling the Gortans Basin, where the minimum on the bottom is 50°·7. Outside, at the same depth, it is 50°, and at the bottom over 47°. Inside it is 46°. There is a very slight rise of the isotherms at Otter.

In the Upper Basin the non-conducting pad of cold water has been practically warmed away; but the minimum temperature, still over 44°, does not yet quite reach the bottom, so that the fall of temperature is not quite uniform from the surface. The isotherms, on the whole, are slightly curved, following the contour of the bottom, and between 50° and 47°, about 30 fathoms, they are most crowded, showing a great mass of warm water passing rapidly into a great mass of cold water. The position of this *Sprungschicht*, as it has been termed in German, is very characteristic just below the lip of the Minard barrier, suggesting that the inflow of warm water from the Gortans Basin spreads over but does not sink through the cold mass filling the Upper Basin.

Section V., 16th–17th November 1886.—In this section cooling from the surface has set in strongly, and the isotherms show some very interesting relations. Outside, the temperature rises to 51°, about 15 fathoms, and remains practically constant, the water growing somewhat warmer toward the bottom. The Gortans Basin is filled with water of the same temperature, the isotherm of 50° falling to the Minard barrier. Inside, the surface temperature falls toward the head of the loch, but the water grows warmer from the surface to about 15 fathoms, where the maximum (about 50°) occurs, and then cools

steadily to 44°·2 at the bottom. In this section we see last winter's cold still undissipated below, but separated from this winter's cold, which is coming in above, by the remains of the summer heat occupying an intermediate position, the freshness of the surface water effectually resisting the formation of convection currents.

Section VI., 29*th–*30*th December* 1886.—Great and general cooling is shown here. Outside, the surface is at 46°·6, the bottom at 47°·4, but just outside the Otter barrier a patch of bottom water above 48° occurs. As no observation was made at Kilfinan, the extent of this can only be guessed.

From Gortans the isotherm of 46° runs almost straight to the head of the loch at a depth of 5 or 6 fathoms, the surface temperature falling below 36°, without, however, sensibly chilling the water below on account of surface freshness. Ice, resulting from the freezing of floating rain or thaw water from land, prevented an examination of the head of the loch on this occasion. The isotherm of 47° slopes up from Minard barrier until it comes close to 46° at Inveraray and beyond. A maximum line of about 47°·5 runs along the loch at about 20 fathoms, and beneath that depth the temperature falls gradually to 44°·8 on the bottom. The isotherms, as a whole, converge toward Minard, and diverge widely toward the head.

Section VII., 4*th–*5*th February* 1887.—Outside, the temperature is somewhat irregular, varying between 44° and 45° from surface to bottom, and the Gortans Basin forms part of the Arran Basin so far as temperature is concerned. A slight upwelling of warmer water from beneath appears at Otter. Inside, the temperature increases from 43° or less on the surface pretty uniformly to 46°·5 at 45 fathoms, then diminishes very gradually to 45°·7 on the bottom. The isotherms generally follow the contour of the bed of the Basin, except for a slight rising of the upper isotherms at Inveraray.

It is noticeable, not only in this, but in almost all the sections, that Gortans Basin is part of the Arran Basin, receiving its surface water, and that the special enclosed character of Loch Fyne begins at Minard.

Section VIII., 29*th March* 1887.—Here a condition of remarkable uniformity prevails. Practically the total range is from 44° to 45°. The surface and bottom of the Upper Basin are at, or slightly above, 45°; the intermediate layers are nearly 44°·5; while the Gortans Basin and the Arran Basin contain water at, and colder than, 44° in the middle.

Here surface heating seems to be just beginning, and a general equalisation of temperature has occurred similar to that of April 1886, although 2° warmer.

Section IX., 10*th May* 1887.—The Gortans Basin is now filled with water of nearly uniform temperature, 46° on surface, 45° on bottom. Outside, it is 46°·3 on the surface, and sinks to an intermediate minimum slightly under 44°. Inside, the surface layers grow warmer toward the head in a remarkable way, the warming, though not spreading down the loch, extending to several fathoms in depth, and the temperature exceeding 50° near Cuill. The isotherm of 45° runs pretty straight from Minard to Cuill at a depth of 20 fathoms. Below that the water cools to a minimum, about 44° at 40

fathoms, and warms to 44°·7 at the bottom, but this intermediate minimum is much less marked than in the previous year.

Section X., 15*th*–16*th June* 1887.—Continued heating has taken place, and in all parts of the section the water now falls gradually in temperature from surface to bottom, all trace of an intermediate minimum having vanished from the Upper Basin, the bottom water in which is, however, a little colder than in the Arran Basin. In the Upper Basin and in the Arran Basin the isotherms on the whole dip seaward, but in the Gortans Basin they dip landward. From Kilfinan to Gortans the disturbance due to the narrow Otter bar is apparent, strong upwelling taking place, while curiously enough there is no disturbance of the isotherms at the Minard passage. Indeed, here Furnace seems the true boundary of the Upper Basin, as the isotherm of 46° reaches the bottom there, and the water down to the bottom remains much over 46° all the way to Otter, beyond which it again sinks. Here at depths below 25 fathoms the Gortans Basin, extended to Furnace, separates two masses of water below 46° by a slice, the temperature of which is from 47° to 46°·8, and the line of 48° sinks deeper in this basin than anywhere else in the section, although the surface temperature above it is only 51° as compared with 57° and 58° beyond Strachur. This is unmistakably a result of the mixed water pouring in past Otter.

Section XI., 7*th*–8*th July* 1887.—Here the conditions of Section X. are accentuated, except the upwelling at Otter, which is scarcely marked.

The surface water at many points is over 60°, forming a very thin hot skin covering the characteristic distribution. In the Upper Basin the isotherm of 50° lies at the depth of about 5 fathoms, scarcely 1 fathom deeper than in June. The isotherm of 46° is only a fathom or two deeper than in June at Strachur and Inveraray, while at Furnace, Dunderawe, and Cuill its position is unchanged, but temperature exceeds 45° down to the bottom, thus showing a slight warming. The very slight effect of the high surface temperature is remarkable. Still more striking is the crowding downward of the isotherms at Furnace, and to a less extent at Otter, leaving the Gortans Basin filled with a huge wedge of water from 1° to 2° warmer than that at like depths outside and inside. The approach to horizontality of the Upper Basin isotherms below the level of the Furnace brow, and the rapid seaward dip of those above it, suggest the advance of a body of warm water and its mixing by lateral translation. As no observations were taken between Furnace and Minard the precise landfall of the isotherms is not known, and the character of X. and XI. may be of much more common occurrence than appears in the earlier sections.

Section XII., 15*th*–16*th August* 1887.—The surface has cooled down a few degrees, but the mass of the water has warmed notably. The isotherm of 50° has sunk to the bottom in the Gortans Basin and to 30 fathoms in the Arran Basin, while from Furnace it curves up toward Cuill. The upwelling at Otter is very slight. The isotherms are closely clustered in the surface zone of 7 fathoms (55° to 52°), then spread more uniformly, clustered again about 25 fathoms (50° to 47°), forming a *Sprungschicht* at Furnace and

Strachur, and below that they are widely spaced. The bottom water of the Arran Basin is now 2° warmer than that in the Upper Basin of Loch Fyne. The drawing of the section between Minard and Furnace is conjectural, and probably incorrect.

Section XIII., 23*rd September* 1887.—Surface temperature has changed but slightly since August, while all the lower isotherms have sunk in fair proportion, indicating a general warming of the lower layers. 50° has reached 60 fathoms at Skate Island and 30 fathoms in the Upper Basin, while the whole Minard Basin is over 52°. The gathering in of isotherms at the bottom at Furnace is more marked than ever, the change from 51° to 48° being compressed into $2\frac{1}{2}$ fathoms compared with 15 fathoms at Inveraray and 30 fathoms at Kilfinan.

Here the pouring in of warm water of uniform temperature seems to take place directly over the cold uniformly-temperatured layer sheltered from mixture by the Furnace brow.

Section XIV., 5*th November* 1887.—This is a partial section from Strachur to the head of the loch. Below 25 fathoms the water has warmed steadily since Section XIII. Above 25 fathoms it has cooled most rapidly on the surface, which is at 46°. The temperature rises rapidly to 50° at about 6 fathoms, then slowly for a fraction of a degree, cools down again to 50° at 23 fathoms, and 49° at 40 fathoms. An excellent example of winter cooling in calm weather, leading to the inclusion of an intermediate maximum.

Section XV., 7*th November* 1887.—In the interval from XIV. a strong gale from north-east (down-loch) prevailed, and the contrast of conditions is singularly instructive. The isotherm of 49° still runs straight across at 40 fathoms, and below it the condition as regards temperature is absolutely unchanged. But above 40 fathoms every trace of thermal stratification has vanished. The temperature rises uniformly to 49°·8 at the surface. Thorough mixture has taken place down to, but not below, the level of the brow at Furnace. This indicates that below 40 fathoms the Upper Basin is extremely isolated, and that complicated circulation and complete mixture may occur in the upper layers without disturbing the depths.

Section XVI., 16*th*–17*th December* 1887.—The bottom water has warmed up to a little over 46°; the surface water has greatly cooled down, especially toward the head of the loch, and there is a rise of temperature from the surface to 48° about 17 fathoms. Nearly constant temperature (a little higher) prevails to 44 fathoms, where it sinks to 48° again, and then falls uniformly to the bottom. Seaward of Furnace the surface temperature ranges from 46° to 47°, but up the loch it falls steadily to 38°·2 at Cuill. The isotherms of 48° in the Upper Basin show a tendency to define a lenticular mass of warmer water, conceivably the remains of the great mixing of November 7th.

Section XVII., 14*th February* 1888.—Great changes have occurred since Section XVI. The surface of the Upper Basin has cooled down to 42° or less, rising rapidly to 46° at 5 fathoms, reaching a slightly higher maximum about 10 fathoms, falling to 46° again at 18 fathoms, and from that position to the bottom remaining nearly constant, falling only

to 45°·3. The centre of this layer of maximum temperature being nearer the surface than that of Section XVI., shows that it is not a result of continuously progressive cooling, but rather due to some more abrupt changes. The marked cooling down to the bottom indicates a once continuous cooling from the surface; the intermediate thin zone of warmer water possibly is all that remains of a surface heating due to warm weather, which, with the recurrence of cold, was capped by a chilled layer. The range of temperature in Gortans Basin and seaward is too slight to be discussed.

Section XVIII., 22*nd*–23*rd March* 1888.—A return to the nearly uniform conditions of the minimum is shown here. The temperature varies from something under 43° on the surface to something over 44° on the bottom. There are traces of a slight intermediate minimum in Gortans Basin, and the accumulation of warmer water on the bottom of the Arran Basin between Otter and Kilfinan is marked, as on several occasions of the approach to minimal conditions.

Section XIX., 2*nd*–4*th June* 1888.—Cooling has continued at the bottom, where the temperature in the Upper Basin is now 43°·3, but rapid heating has gone on from above downward without the formation of any trace of an intermediate minimum. The section is largely hypothetical, as no observations were made at Furnace, Minard, or Otter.

Sections XX. and *XXI.* (*Partial Sections*), 24*th*–25*th August* 1888; *XXII.*, 27*th August* 1888.—On the 24th there was a rapid fall from 60° on surface to 54° at 1½ fathom, a gentle fall (50° at 15 fathoms) to 48° at 22 fathoms, rapid fall to 46° at 23½ fathoms, and finally a gentle fall to 44° at 35 fathoms.

On the 25th the surface temperature was somewhat higher, and the fall of temperature at the greater depths much more uniform, the crowded isotherms 48°–46° being in particular well spread out. The range of temperature was remarkable.

On the 27th the downward propagation of warmth was very clearly marked; and the surface layers having cooled somewhat, an intermediate maximum was formed at about 3 fathoms at the head of the loch.

Section XXIII., 16*th*, 17*th*, 18*th*, and 19*th October* 1888.—This section was compiled from observations scattered over too long a time to be of much value. It appears to show the characteristic signs of a flow of warm water from the Gortans Basin over Furnace brow into the Upper Basin. The upper strata of water are assuming the homothermic form common in autumnal cooling.

The difference between the thermal changes in the Arran Basin and Loch Fyne is mainly due to the restricted entrance and the much steeper slope within the sill preventing the free mixture of the water from outside, and also to the low salinity of the surface water in the upper reaches. The resemblance of the Channel and Plateau to the Gortans Basin is very strong. The upwelling at Otter keeps the Gortans Basin supplied with nearly homothermic water of much greater salinity than that found at the same depth in the Upper Basin, but on account of the steep slope beyond Furnace this water appears to spread over the cold layers of Loch Fyne, instead of following the ground and

gradually mixing with the mass down to the bottom. There is, indeed, a certain amount of mixture, as is proved by the variations in the salinity of the deep water. How far this is due to tidal action we cannot say. Wind is certainly a more powerful agent for setting up vertical currents in the water than tide is, but a steady wind in one direction rarely lasts long enough to produce its full effect. The tides, on the other hand, act continuously, and I have by further consideration been led to modify the opinion stated in Part II. p. 706, that tidal influence was insignificant as leading to the formation of deep currents in the Upper Basin. I do not find in the temperature observations enough data to found an exact theory upon, and the precise share of steady tidal action and spasmodic wind-action in stirring the depths of the Upper Basin must remain for the present undetermined.

Table XXXIV. shows that even with constant temperature there is not stagnation at the bottom.

TABLE XXXIV.—*Bottom Salinity and Temperature.—Strachur.*

	April 1886.	June 1886.	Aug. 1886.	Sept. 1886.	Nov. 1886.	Dec. 1886.	Feb. 1887.	March 1887.	May 1887.	June 1887.	July 1887.	Sept. 1887.	Average.
Density at 60° F.	1·02450	1·02481	1·02517	1·02483	1·02422	1·02472	1·02441	1·02430	1·02447	1·02477	1·02479	1·02472	1·02465
Temperature *in situ.*	41·9	44·1	44·2	44·1	44·2	44·7	45·9	45·5	44·7	45·2	45·2	45·3	44·6

Here we see that there were variations in the bottom salinity from its minimum to its maximum value during the period of constant bottom temperature, June to November 1886; and this fact shows that the exchange of water with the outside must have been very uniform and gentle indeed. The intermediate belt of minimum temperature would provide in June and August a means of chilling the warm dense Gortans Basin water as it sank, so that it would not carry its original temperature down with it, but between September and November no such explanation offers. The period June to September 1887, when the temperature was constant, was also characterised by uniform salinity, and, but for the contradiction of the previous year, would have justified a presumption that constant bottom temperature indicated stagnation.

Seasonal Variations of Temperature in the Mass of Water in Loch Fyne.—From the temperature sections the mean temperature of the whole mass of water in Loch Fyne from Otter to the head was calculated for each trip in the manner already explained (p. 10). The temperature of each layer of 10 fathoms was estimated by measuring the areas between successive isotherms, and the resulting figures were "weighted" by multiplying each with a factor representing the relative volume of the layers, and dividing the sum of the products by the sum of the factors. The factors in the case of Loch Fyne were :—

Layer in fathoms,	0–10	10–20	20–30	30–40	40–50	50–60	Over 60
Factor, . .	15·5	13·3	9·5	4·9	3·0	2·1	1·0

And if the mean temperatures for the several layers were a, b, c . . . the weighted mean temperature (T) of the whole mass is given by

$$T = \frac{15{\cdot}5a + 13{\cdot}3b + 9{\cdot}5c + 4{\cdot}9d + 3{\cdot}0e + 2{\cdot}1f + g.}{49{\cdot}3}$$

TABLE XXXV.—*Mean Temperature at various depths in Loch Fyne.*

Section.	Date.	Days since last Trip.	Mean Temp. Weighted.	Mean Temperature of Layers.						
				0–10	10–20	20–30	30–40	40–50	50–60	Over 60
I. . .	20.4.86	...	42·06	42·52	42·00	41·88	41·76	41·63	41·56	41·50
II. . .	21.6.86	62	44·43	46·25	43·56	43·40	43·56	43·90	44·05	44·10
III. . .	10.8.86	50	47·94	51·18	48·25	46·45	44·54	44·01	44·12	44·18
IV. . .	27.9.86	48	49·85	52·18	51·40	49·27	46·19	44·70	44·13	44·00
V. . .	16.11.86	50	49·02	48·84	49·91	49·81	49·71	46·58	45·15	44·50
VI. . .	29.12.86	43	46·44	45·46	47·04	47·19	47·05	46·44	45·60	45·05
VII. . .	4.2.87	37	44·74	43·73	44·58	45·00	45·97	46·40	46·19	46·04
VIII. . .	29.3.87	53	44·40	44·47	44·30	44·31	44·36	44·54	44·60	44·80
IX. . .	10.5.87	42	45·35	46·52	45·24	44·67	44·30	44·40	44·59	44·68
X. . .	15.6.87	36	47·74	50·60	47·69	46·77	46·00	45·12	44·93	44·80
XI. . .	7.7.87	22	48·81	51·78	48·44	47·80	46·67	45·43	45·30	45·20
XII. . .	15.8.87	39	50·29	53·30	50·75	49·31	47·16	45·98	45·56	45·15
XIII. . .	23.9.87	39	51·42	53·22	52·30	51·63	49·28	46·89	46·00	45·40
XIV. . .	16.12.87	84	47·23	46·00	47·56	48·03	48·12	48·00	47·55	47·00
XV. . .	14.2.88	60	45·37	45·02	45·68	45·52	45·37	45·40	45·35	45·30
XVI. . .	22.3.88	36	43·33	43·10	43·18	43·37	43·65	43·90	44·00	44·00
XVII. . .	2.6.88	73	45·36	46·22	45·47	44·68	43·95	43·60	43·40	43·30
XVIII. . .	16.9.88	106	48·71	49·83	49·64	48·79	47·31	45·40	44·80	43·50

Table XXXV. gives for each of the eighteen complete sections the date, number of days elapsing since previous trip, the weighted mean temperature of the mass of water, and the actual mean temperature of the seven ten-fathom layers. A selection of these figures is represented graphically in the curve, fig. 41, Plate XXX. On this curve also the mean temperature of the air at Callton Mor is given as an indication of the actual air-temperature over Loch Fyne. The air-temperature has the greatest range and is the earliest in phase; the surface layer of 5 fathoms follows the air-temperature with a much diminished range, its maximum occurring 45 days later in 1886, and about 50 days later in 1887. The minimum is not easily compared, as the air-temperature on both occasions showed a double minimum three months apart, the surface-water minimum occurring between the two in 1887, and coincidently with the later air-minimum in 1888. The water at 35 fathoms deep (mean of the layer 30 to 40 fathoms) had a less range, and its maximum was retarded 126 days after the air-maximum in 1886 and about 120 days in 1887. The minimum was 75 days later than that of the surface water in 1887, but synchronised with it in 1888. The bottom layer of 10 fathoms showed a very small range. The maximum was retarded 212 days after the air-

maximum in 1886, and 185 days in 1887. The minimum similarly occurred about six months later than the minimum on the surface. The curves show considerable irregularity, particularly the bottom curve, for successive years; but the general facts of retardation of phase and reduction of range with depth are clearly brought out. The retardation of the annual maximum with depth is expressed graphically in fig. 42, Plate XXX, where depths are ordinates, and the time, in days after the occurrence of the maximum annual temperature at 5 fathoms, are abscissæ. In 1886 the bottom was 120 days behind the surface layer, in 1887 only 95 days. In 1886 the phase was simultaneous at 5 and 15 fathoms, in 1887 thirty days were required for the maximum to sink to the latter depth. But in 1887 ten days more saw the maximum at 25 fathoms, while in 1886 twenty days were necessary. From 35 to 45 fathoms the descent of the maximum was at the same rate in both years, and 14 days more brought it to the bottom in 1887, while 48 days were necessary in 1886. The curves at all depths are, as in all cases, widely spread in heating up, and drawn much closer together while cooling down. The approximation is more apparent for curves of middle and bottom temperature, the surface remaining markedly higher during heating and lower during cooling, probably on account of the much lower salinity of the surface layer. The variations of the temperature of the water of the loch as a whole are much more regular than those of the separate layers, and admit of comparison with those of the Channel and Arran Basin, with which they are compared in Table LXIV. in the General Summary.

Starting from a minimum of 42°, say on April 15th, 1886, the mass of water came to its maximum of 49°·9 on September 30th, a gain of 7°·9 in 168 days, or an average of 0°·047 per day. This time of heating is practically the same as that for the Arran Basin, but the rise of temperature was 1°·7 less, or 5°·1 less than was gained by the Channel water, starting from the same minimum in 20 days less time. The daily gain was one-fifth less than in the Arran Basin, and practically only one-half of that in the Channel. The minimum (probably 43°·8) was reached on March 5th, 1887, showing a total loss of 6°·1 in 156 days, or of 0°·039 per day on the average. Here also the period of cooling was practically the same as that in the Arran Basin, although the minimum was slightly higher, and the daily fall of temperature one-quarter less. The next maximum occurred on September 27th, 1887, when the temperature was 51°·5, showing a gain of 7°·7 in 206 days, at the rate of 0°·037 per day. Here the rate of heating bore the same relation as before to that in the Channel and Arran Basin, but the period of heating was proportionally longer. A minimum of 43°·2 on March 30th showed the loss of 8°·3 in 184 days, or 0°·045 per day. This rate of cooling was almost as rapid as in the Arran Basin, and its duration 15 days less. The last maximum observed (48°·7 on September 15th, 1888) showed a gain of 5°·5 in 170 days, or at the rate of 0°·033 per day. The mean duration of heating in Loch Fyne for the three years observed was 180 days, and for cooling in the two years 170 days. For the two years in which the observations for the three years are comparable the ratio of the period of heating to that of cooling was 100 : 115 in the Channel, 100 : 100 in the Arran Basin,

and 100 : 91 in Loch Fyne. Thus it appears that increasing isolation tends to increase the period of gain of heat by retarding the date of maximum and reducing the rate of gain of temperature.

The rate of heating at various depths, and for the mass of water as a whole, is given in Table XXXVI., and represented graphically in fig. 5, Plate IV. This shows that the mean rate of heating per day is greater than that of cooling in the upper half of the water, but less than the rate of cooling in the lower half. It also shows that the rate of change of temperature is on the average 0°·040 per day for the whole mass of water, corresponding to 1° in 25 days. For the surface layer of 10 fathoms it is 0°·053, or 1° in 19 days (maximum, May to August, 1° in 10 days heating, and October to December, 1° in 12 days cooling); half way down it is 0°·033 per day, or 1° in 30 days; and at the bottom only 0°·015 per day, or 1° in 66 days. Plotting these figures—the average daily change of temperature for the whole period—as abscissæ, with depths as ordinates, we see in fig. 43, Plate XXX., how the restriction of thermal change goes on increasingly until 40.

TABLE XXXVI.—*Average Change of Temperature* per diem *in Loch Fyne.*

Dates.	No. of Days.	Change of Temperature in Degrees per Day.							
		Mass.	0–10 Fathoms.	10–20 Fathoms.	20–30 Fathoms.	30–40 Fathoms.	40–50 Fathoms.	50–60 Fathoms.	Over 60 Fathoms.
21.6.86	62	+0·038	+0·060	+0·025	+0·024	+0·029	+0·037	+0·040	+0·042
10.8.86	50	+0·070	+0·099	+0·094	+0·061	+0·020	+0·002	+0·001	+0·002
27.9.86	48	+0·040	+0·021	+0·066	+0·059	+0·034	+0·014	0·000	−0·004
16.11.86	50	−0·017	−0·067	−0·030	+0·011	+0·070	+0·038	+0·020	+0·010
29.12.86	43	−0·060	−0·079	−0·067	−0·061	−0·062	−0·003	+0·010	+0·013
4.2.87	37	−0·046	−0·047	−0·067	−0·059	−0·029	0·000	+0·016	+0·027
29.3.87	53	−0·006	+0·014	−0·005	−0·013	−0·030	−0·035	−0·030	−0·023
10.5.87	42	+0·023	+0·049	+0·022	+0·009	−0·001	−0·003	0·000	−0·002
15.6.87	36	+0·066	+0·097	+0·068	+0·058	+0·047	+0·020	+0·009	+0·003
7.7.87	22	+0·049	+0·081	+0·034	+0·047	+0·030	+0·014	+0·017	+0·018
15.8.87	39	+0·038	+0·039	+0·059	+0·039	+0·013	+0·014	+0·006	0·000
23.9.87	39	+0·029	−0·002	+0·040	+0·059	+0·054	+0·023	+0·011	+0·006
16.12.87	84	−0·050	−0·086	−0·056	−0·043	−0·014	+0·013	+0·018	+0·019
14.2.88	60	−0·031	−0·016	−0·031	−0·042	−0·046	−0·043	−0·036	−0·028
22.3.88	36	−0·057	−0·054	−0·069	−0·060	−0·048	−0·042	−0·037	−0·036
2.6.88	73	+0·028	+0·043	+0·031	+0·018	+0·004	−0·004	−0·008	−0·010
Mean Heating . .		+0·042	+0·056	+0·049	+0·038	+0·033	+0·019	+0·015	+0·015
No. of Cases . .		9	9	9	10	9	9	10	9
Mean Cooling . .		−0·038	−0·050	−0·046	−0·046	−0·033	−0·022	−0·028	−0·017
No. of Cases . .		7	7	7	6	7	6	4	6
Mean Change . .		0·040	0·053	0·048	0·041	0·033	0·019	0·016	0·015

fathoms, where the mean daily change is only half that at the surface, and then the rate of change diminishes, until at 70 fathoms it is rather less than one-third as great as at the surface, and appears to approach a limiting value. This curve appears to indicate that no increase of the depth of Loch Fyne would suffice to absolutely prevent the influence of surface change of temperature from affecting the deepest water. It furnishes another proof of the necessity of caution in generalising from incomplete results; for if observations had only been carried to 50 fathoms, it would have appeared probable that before 60 fathoms constant temperature would be reached.

As in the Arran Basin, the air-temperature curve for Loch Fyne cut the surface curve at the maximum, and the mean curve rather after the maximum. The theoretical reason of this coincidence is obvious. The surface water continues slowly to rise in temperature while the air is cooling down, as long as the actual temperature of the air is above that of the surface, but as soon as the cooling air reaches the same temperature as the water this rise ceases, and as the air becomes colder it chills the surface layers by contact, and causes the first fall of surface temperature. On the other hand, the cooling of the water appears to be checked at the minimum by the heating power of the sun, and the air does not become warmer than the water until the latter has begun slowly to heat up. As in the curves for the Arran Basin, the surface-water temperature in rising is, after the air-curve crosses it, almost the exact mean between the air-temperature and that of the mass of water.

During the rise of temperature the air was warmer than the surface water for 165 days in 1886, 120 days in 1887, and 150 days in 1888, an average of 145 days; and during the rest of the time the air was colder than the surface water for 216 days in 1886–87, and for 222 days in 1887–88, an average of 219 days. Speaking roughly, we may say that the air is warmer than the surface water for four and a half months, from the beginning of May to the middle of September, and colder for the seven and a half months from the middle of September to the end of April. The number of days when air was warmer than water for the two seasons 1886–88 were, for the Channel, Arran Basin, and Loch Fyne respectively, 134, 136, and 143; while for air colder than water they were 237, 228, and 219. This effect of isolation in lengthening the period in which the air is warmer is evidently due to the lower maximum resulting from a slower rate of rise of temperature, giving a longer interval before the falling air-temperature reaches the same value and stops further rise of temperature.

By interpolating probable values for the first three months of 1886, it is possible to compare the annual mean temperatures of the two years; and by interpolating probable values for the last three months of 1888, the hypothetical annual means for three years may be compared.

Hence each year the surface water was warmer on the average than the air, so that it exercised, on the whole, a warming influence on the atmosphere, while the mass of water, as a whole, was very little warmer than the air, and in 1888 appeared to be a little colder. In 1886 the excesses of temperature of the surface water over the air in

the Channel, Arran Basin, and Loch Fyne were respectively 1°·7, 1°·2, 1°·3; and in 1887, 1°·7, 2°·3, 1°·7; or on the average of the two years, 1°·7, 1°·7, 1°·5. The figures for the Arran Basin are probably the least trustworthy; but it appears that the isolation of Loch Fyne has practically no effect on the relation between the temperature of the lower strata of the air and the upper strata of the water. The difference produced by

TABLE XXXVII.—*Mean Annual Temperatures of Air and Water for Loch Fyne.*

Year.	I. Air (mean for Area).	II. Air (Callton Mor.).	III. Water. Surface 5 fathoms.	IV. Water. Mass.	Difference between Air II. and Water III.	Air II. and Water IV.
1886	46·2	45·5	46·8	45·8	−1·3	−0·3
1887	47·0	46·9	48·6	47·5	−1·7	−0·6
1888	46·7	46·6	47·1	46·0	−0·5	+0·6
Mean.	46·63	46·33	47·50	46·43	−1·17	−0·10

isolation comes out on comparing the excess of warmth of the mass of water in each division over that of the air. On the average of 1886 and 1887, this factor for the Channel, Arran Basin, and Loch Fyne was 1°·7, 0°·35, 0°·45. Here the great depth of the Arran Basin, and the uncertainty as to the true air and water mean temperatures, prevent us from accepting its figure as of equal value with the other two.

THE GARELOCH.

This division is defined as the area lying north and west of Row Point. It is five miles long, and less than one mile wide at the widest. Outside Row Point a wide and comparatively shallow basin communicates directly with the Estuary. The tides run strongly into and out of the loch. The configuration of the loch is described in Part I. p. 646, and sections given in No. 17, Plate 9 of that instalment. The area is 4·23 square miles, with a land drainage of 12·40 square miles. The ratio of water to total drainage-area is 1: 3·93, and is the largest ratio of any of the lochs.

The Gareloch is characteristically shallow and flat-floored, with gently sloping banks, forming a single basin with a clearly defined bar. Its mean axial depth is 18 fathoms, and its average depth only 7 fathoms. The tidal rise is 9 feet.

In the Gareloch the average percentage of pure sea-water was found to be 89·6 per cent. by volume. It is the freshest of the divisions of the Area, and is situated in a landward position, exposed to a considerable range of climatic conditions. It may be considered in this place as a fourth and distinct type, showing temperature changes quite different from those of the Channel, Arran Basin, or Loch Fyne.

Observations at Row I.—This station is situated outside the Gareloch, with Row

Beacon bearing N. one-sixth mile. The depth is 12 fathoms, in an isolated patch shoaling inward to a shallow bar, and more gently seaward to a plateau of the minimum depth of 8 fathoms, beyond which a tongue of deeper water leads westward to Dunoon Basin, while it shoals eastward into the estuary. The average density of the water was :—

	Surface.		Bottom.
Mean (7 observations) . . .	1·02223	...	1·02407
Maximum	1·02387	...	1·02477
Minimum	1·01985	...	1·02367

The average percentage of pure salt water at "Row" was 85·7 at surface, 91·3 at bottom, or 90·4 in vertical section, and it may be assumed for an ordinary year as 90·1.

TABLE XXXVIII.—*Temperature Observations at Row I.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date . .	13.4.86	16.6.86	4.8.86	24.9.86	11.11.86	28.12.86	25.3.87	6.5.87	13.6.87	6.8.87	29.11.87	9.2.88	28.3.88	6.9.88
No. of Pts.	3	3	4	4	4	6	7	2	3	8	6	6	3	6
Temp. . .	42·3	48·7	51·6	53·1	50·2	44·0	43·0	46·1	51·0	55·8	47·7	44·5	41·8	53·7
Slope . .	+1·0	+0·4	+0·3	+0·1	−1·1	−0·8	−0·2	+0·9	+0·6	+1·6	−1·0	−0·5	−0·1	+1·0

The curves which were drawn from the observations were uniform in all cases except No. 14, where the temperatures at surface, 5 fathoms, and bottom were 41°·9, 41°·6, and 42°·2, showing an intermediate minimum; but as only three points were determined, this may be neglected. Nos. 1, 2, 3, 4 showed a successive reduction of positive slope; No. 4, the maximum for the year, being practically homothermic; Nos. 5 and 6—the cooling curves—were of greater range relatively, showing a marked negative slope; but No. 7 was again almost homothermic, this time at the minimum. Nos. 8, 9, 10 had increasing positive slope as warming continued, No. 10—the maximum—showing a range of 3° in 10 fathoms; Nos. 11 and 12 showed diminishing negative slope; and No. 13 is again a homothermic minimum.

The greatest range between surface and bottom temperatures was 4°·8, on 29th November 1887, in 11 fathoms, the bottom being warmer; 3° of the change took place in the first fathom. The effect was that naturally due to rapid surface-cooling. The comparatively small vertical range in the curves, as a whole, is readily accounted for by tidal mixture.

The maximum temperature of the mass of water was 55°·8 in August 1887, and the minimum 41°·8 in March 1888. Of the 15 soundings, 9 were made in the summer and 6 in the winter half-year, the water warming in the former, and cooling in the latter season. The period of observation included three minima (in March or April) and three maxima (in August or September).

Observations at Row II.—The observations were made just inside the Gareloch, Row

Beacon bearing S. ½ mile. The depth was 23 fathoms, the fall from the bar at the mouth of the loch off Row Point being very abrupt to this point, but the loch then remains almost of the same depth, forming a single trough all the way to the head. The average density of surface water from four observations was 1·02254, maximum 1·02387, and minimum 1·01985; and on the bottom the mean from five observations was 1·02341, with a maximum of 1·02380, and a minimum of 1·02239.

The surface water is practically identical in salinity with that of Row I., but the bottom water is considerably fresher, as might be expected.

TABLE XXXIX.—*Temperature Observations at Row II.*

No. . . .	1	2	3	4*	5	6	7	8	9	10	11	12	13	14	15	16
Date . .	13.4.86	16.6.86	4.8.86	11.11.86	28.12.86	2.2.87	25.3.87	6.5.87	13.6.87	6.8.87	30.9.87	29.11.87	9.2.88	28.3.88	7.6.88	6.9.88
No. of Pts.	5	4	7	4	6	6	3	4	3	6	4	3	6	3	6	3
Temp. . .	41·8	48·3	52·6	49·4	44·4	42·9	42·9	45·9	50·6	57·6	53·9	46·6	44·0	41·9	46·3	54·1
Slope . .	+1·6	+1·0	+0·6	...	−1·3	−1·0	0·0	+0·9	+1·0	+0·4	−0·1	−1·8	−0·3	−0·1	+1·3	+1·3

* To 10 fathoms only.

Three observations, those of December 1886, February 1887, and February 1888 show mixed slopes indicating the existence of intermediate layers at different temperatures. Nos. 1, 2, and 3 showed positive slope with diminishing range, the greatest range of the whole series being No. 1 of 2°·7; at surface, 44°·1; at bottom, 41°·4; and of this there was a range of 2° in the first 4 fathoms. The small maximum range of 2°·7 in 20 fathoms is a distinct feature of this set of curves.

In order to determine the relation to season of the positive and negative slopes, a curve (fig. 44, Plate XXX.) was constructed, showing positive slope by the difference (drawn above mean line) between the warmer upper 5 fathoms and cooler lowest 5 fathoms; and negative slope by the difference between the colder upper 5 fathoms and warmer lower 5 fathoms.

Fig. 44 shows the seasonal change of slope for both Row II. and Shandon. At both stations the curve of slope cuts the zero line about the equinoxes, showing that as long as the period of daylight is greater than that of darkness, the surface water as a whole is warmer than that beneath; but when the period of darkness exceeds that of daylight, the surface water becomes colder than that below. The period of greatest negative slope appears to occur in December about the time of the winter solstice. In 1886 the maximum positive slope occurred nearly at the summer solstice, but in both the other years it was delayed until the month of August, showing that the surface water continued to gain heat rapidly for two months after the summer solstice. The curve cut the zero line in ascending at or before the annual minimum of temperature, and cut it in descending at or after the annual maximum.

The curve of seasonal change of mean temperature ran on the whole parallel to that

of Row I. (*q.v.*) and included three minima and three maxima, but unfortunately neither maxima nor minima were fully mapped out by observations. The mean temperature was throughout somewhat lower than that of Row I. The mean of the 16 average vertical temperatures was 47°·7, or 0°·4 lower than for Row I. Of the 16 soundings, 9 were in the summer and 7 in the winter half-year. Omitting two soundings which were not represented at Row I., the mean for Row II. comes out as 47°·6, or 0°·5 lower than that for Row I., it being thus apparent that the station inside the barrier was distinctly colder than that outside, largely of course on account of the much greater depth.

The strong tidal stream running into and out of the narrow and shallow mouth of the Gareloch produces a distinct effect in mixing the water vertically, and when a breeze is blowing against the tide, the commotion produced is very considerable.

No special observations were made as to temperature, but the appearances were exactly similar to those at Otter Spit (see Loch Fyne), which were carefully investigated. Comparison of the various sections will show how those at Row differ from the others.

Observations between Barreman and Clynder.—A few observations were taken at this point, about midway between Row II. and Shandon, in the form of a cross section, which is of value as showing the relation of axial to lateral vertical temperature curves, and giving some information as to the form of the isothermal sheets. The observations were practically simultaneous, that off Barreman pier in 2 fathoms being made at 13^h15, the three deep-water soundings at 13^h30, 14^h0, and 14^h20, and the others immediately after. They were made on June 7th during a strong easterly breeze, the "Medusa" going against the wind from the lee to the weather shore.

The vertical curves were defined by very numerous observations, so that a cross section could be drawn with some confidence.

The data are as follows. Air temperature, 52°·1 :—

TABLE XL.—*Cross Section of Gareloch at Clynder.*

No. and depth	1 (2 fms.)	2(13 fms.)	3(16 fms.)	4(12 fms.)	5 (3 ?)	6 (6 fms.)	7 (4 fms.)
No. of points	2	9	9	9	3	6	3
Temperature, surface	48·3	48·0	47·3	47·5	47·4	47·0	47·0
Temperature, bottom	48·3	46·1	45·9	46·1	47·1	46·6	46·9
Temperature, mean	48·3	46·7	46·4	46·6	47·3	46·8	46·9

The diminution of mean temperature is here uniform with the increase of depth. At this point the width of the loch is exactly 1 mile.

From the curves a section (fig. 45, Plate XXXI.) was drawn on a large scale, the isotherms of each quarter of a degree being represented upon it. On account of the great closeness of the thermometer readings, this could be done with considerable exactness. The result showed a remarkable decrease of temperature to windward, most rapid near

both shores, and least in the centre. . The isotherms dipped from the west shore up to the surface, showing a greatly thickened layer of warm water against that shore. The temperature of 47° left the west side at 5 fathoms, crossed the centre at 4 fathoms, and curved up sharply to the surface at Station 6. While the isotherm of 46°·75 ran parallel half a fathom deeper from the west shore to Station 4, whence it rose to $3\frac{1}{4}$ fathoms at Station 6, and thence dipped to 4 fathoms at the eastern shore; the line of 46°·5 ran on the whole parallel and about half a fathom deeper, and below it the fall of temperature was gradual, the isotherms being highest in the centre and lowest at both sides. Two bands of close-clustered isotherms cross the section, showing two planes of juxtaposition of layers of unequal temperature; between these are the thoroughly mixed areas, which occur on the west shore, in the centre, and on the east shore. On the west side of the central line the temperature rises toward the west shore at every level, showing a descent and banking up of the warmer upper layer. On the east side, from 4 fathoms to the surface the temperature was practically uniform, and cooler than the rest of the surface, showing an upward movement, but more feeble than that in the centre; and below 4 fathoms the isotherms dip down from the centre eastward as well as westward, showing the descent of warmer water along the windward side.

The natural conclusion to draw from this is that at about 5 fathoms the windward side is divided into an upper zone of direct wind circulation, and a lower zone or eddy of inverted wind circulation, as shown roughly on the diagram fig. 39, Plate XXIX., while the leeward side has a complete system of direct circulation, the power of the wind causing an upward current in the centre as well as against the shore.

Observations at Shandon.—Soundings were made in mid-channel off Shandon Pier, in line with Mamore Farm on the opposite side, in a depth of 21 fathoms. About a quarter of a mile higher up, the greatest depth (23 fathoms) occurs. Sections are given in Plate 9, fig. 17B, in Part I.

The density of the water was as follows:—

	Surface (10 observations).	Bottom (9 observations).
Mean,	1·02233	1·02353
Maximum,	1·02378	1·02398
Minimum,	1·01914	1·02323

The bottom water of the Gareloch is the least dense of any in the Clyde Sea Area, excluding the estuary.

The great range between the temperature of surface and bottom layers is noticeable, particularly in the cases of maximum positive slope in early summer; but the form of the curves is of interest as well. Nos. 1, 5, 18 may be excluded from consideration on account of the small number of observations made, and in the case of No. 5 on account of the very exceptional form. No. 18 showed the maximum positive slope, 3°·6 in 20 fathoms, but No. 12, with 3°·2, is more trustworthy. The maximum negative slope was 2°·4, shown in No. 7. Both maximum positive slopes occurred in August (1887 and 1888)

and two maximum negative slopes in November, the third in December. But in August 1886 the positive slope was only 0°·6, and the curve below 2 fathoms (Nc. 4) was practically homothermic. This was probably an accidental result, due to temporary mixture by winds.

There were two well-marked types of curve at this station, one paraboloid or approaching the hyperbola, the other S-shaped, and at opposite seasons both curves

TABLE XLI.—*Temperature Observations at Shandon.*

No.	1	2	3	4	5	6	7	8	9	10	11
Date	13.4.86	21.4.86	16.6.86	3.8.86	24.9.86	11.11.86	28.12.86	2.2.87	25.3.87	6.5.87	13.6.87
No. of Points	3	7	6	7	4	6	6	6	6	6	9
Temp.	41·4	42·0	47·6	52·9	54·4	50·5	44·4	43·1	42·9	45·7	50·4
Slope	+1·9	+1·2	+1·8	+0·6	+0·7	−1·7	−2·4	−1·0	−0·1	+1·6	+2·8

No.	12	13	14	15	16	17	18	19	20	21	...
Date	6.8.87	30.9.87	29.11.87	9.2.88	28.3.88	7.6.88	20.8.88	6.9.88	22.10.88	25.10.88	...
No. of Points	9	4	6	6	3	6	3	6	6	6	...
Temp.	57·4	54·1	46·8	43·8	42·0	46·5	52·8	53·6	49·9	50·0	...
Slope	+3·2	−0·2	−1·7	−0·3	−0·1	+1·3	+3·6	+2·0	−0·3	−0·1	...

showed reversed slopes. These forms were only hinted at in the Row II. observations. Representative examples are given in fig. 46, Plate XXXI. Nos. 7 and 10 were the two best marked hyperbolas. No. 7 (December 1886) was a cooling curve of high negative slope; it indicated the existence of 5 fathoms of surface water (from 41° surface to 44°·1), showing a rapid rise of temperature with depth, separated by an intermediate layer from 10 fathoms of almost uniform temperature (44°·9 to 45°·1). No. 10 is a warming curve (May 1887), showing high positive slope. The change here is remarkably abrupt. From the bottom at 20 fathoms to 5 fathoms the temperature rises only from 45°·2 to 45°·3, showing that three-quarters of the mass is homothermic. From the depth of 3 fathoms, with temperature 45°·6, the water heats rapidly to 49°·3 on the surface. In this case three observations—surface, 5 fathoms, and bottom—would have sufficed to determine the true character of the temperature distribution, but if the three observations had been at any intermediate position, they would have been misleading.

The S-shaped curve was shown fairly well in the central stations of the Clynder observations. It indicates a stratified or heterothermic arrangement of layers of water at different temperatures. The best examples shown at Shandon were Nos. 6 (negative) and 3, 11, and 12 (positive). Here many and close observations are required to define the various inflections, and No. 11 is the best. The typical S-curve shows the following

peculiarities. The curve of mean temperature is a straight line passing through the surface, centre, and bottom of the S. In the positive curve the upper 10 fathoms show temperatures below the mean curve, the lower 10 fathoms show temperatures correspondingly above the mean. The positive curves of this type occurred in June and August, the negative in November. They show typically in summer rapidly warming surface and bottom water, and a large mass of nearly uniform temperature between, colder than the surface and warmer than the bottom layer.

The mean temperature of 20 soundings (12 in the summer, 8 in the winter half-year) was 48°, maximum 57°·4 in August 1887, minimum 41°·4 in April 1886.

Partial Cross-Section on June 7th, 1888.—At 12^{h}15 a sounding was made at the deepest point in mid-channel, and at 12^{h}40 another off Shandon Pier in 6 fathoms. The former showed much higher temperatures at the same depth, the isotherms sinking abruptly to windward. At 15^{h}40 a sounding was made in 4 fathoms off the pier, and at 16^{h}10 another on the western and leeward shore directly opposite. This showed a well-marked rise of temperature on the leeward as compared with the windward shore. In the three hours, however, the temperature off Shandon had risen 1°, and the dip of the isotherms was altered. Hence the section which was drawn cannot be compared with that off Clynder, although it appears to show similar features in a less marked way.

On October 22nd, 1888, at 11^{h}20, wind E., very light, and on October 25th at 11^{h}10, wind S.W. by S., a stiff breeze, observations were made with great completeness. The mean temperatures as deduced from these curves was practically the same, 49°·9 for the former, 50°·0 for the latter, so that, on the whole, they represent a complete cessation of cooling during three days in Autumn. The average temperature of the lowest 5 fathoms was unchanged, that of the superficial 5 fathoms was uniformly raised by 0°·2, a result probably due to the surface action of the strong wind blowing up the loch on the second occasion. The intermediate layer was slightly cooler on the second occasion, evidently showing that in the three days there had been first cooling down to at least 10 fathoms, where it must have amounted to more than 0°·1, and subsequently a uniform warming of the surface layers.

The relation of change of temperature to depth and time at Shandon is shown in the diagram fig. 9, Pl. V., in which the tendency towards homothermic change of temperature is made evident. Only at the maximum of 1887 and 1888, and at the minimum of 1888, are there clear traces of change of temperature taking place much more rapidly on the surface than at the bottom.

Observations at Garelochhead.—Soundings were made in mid-channel, $\frac{1}{3}$ of a mile from the head of the loch in a depth of 10 fathoms, shoaling rapidly to the head. (See section 17A, Pl. 9, in Part I.) The average density of the water at this station was as follows :—

	Surface, 11 observations.	Bottom, 9 observations.
Mean,	1·02238	1·02339
Maximum,	1·02390	1·02396
Minimum,	1·01913	1·02287

The average density at the head was greater than that at Shandon, but the extremes were also greater.

TABLE XLII.—*Temperature Observations at Garelochhead.*

No.	1	2	3	4	5	6	7	8	9	10
Date	13.4.86	21.4.86	16.6.86	3.8.86	24.9.86	11.11.86	28.12.86	2.2.87	25.3.87	6.5.87
No. of Points	4	7	4	4	4	3	6	3	3	5
Temperature	41·6	43·0	47·9	53·1	53·9	50·1	43·8	42·9	43·0	46·4
Slope	+1·1	+1·8	+0·6	+0·4	−0·2	−0·7	−1·8	−0·7	−0·1	+1·8

No.	11	12	13	14	15	16	17	18	19	...
Date	13.6.87	6.8.87	30.9.87	29.11.87	9.2.88	28.3.88	7.6.88	20.8.88	6.9.88	...
No. of Points	3	6	4	3	3	3	3	3	3	...
Temperature	51·0	58·5	54·4	44·9	43·6	41·7	47·7	55·7	54·8	...
Slope	+0·7	+1·2	−0·1	−1·7	0·0	0·0	+0·9	+2·4	+0·5	...

The mean of these curves gives 48°·3 as the average temperature of the station, which is a little higher than any other average temperature in the loch; the range from 41°·6 in April 1886 (41°·7 in March 1888) to 58°·5 in August 1887 is also the largest found.

On account of the slight depth comparatively little interest attaches to the form of the individual curves, which were only delineated satisfactorily in a few cases. So far as the depth admitted, the forms of paraboloid and S-shaped curves, and the changes of slope, were shown as at Shandon. No. 12 is an interesting case of a paraboloid curve formed perfectly from 2 fathoms downwards, but turned up abruptly to the surface where the temperature was 3° lower than the rest of the curve would lead one to expect. The correctness of surface temperatures, as a rule, is open to doubt. In curve 10, for instance, a surface reading, when the observations began, gave 52°, and when they were over, only 50°5. A further fall of 0°·9 would have given the same form of curve as in No. 12. No. 10 was made at 16^h40 on May 6th, 1887, No. 12 on August 6th, 1887, at 13^h45 in rain.

The three maxima embraced by the observation show Garelochhead to have the highest temperature, and Row I. the lowest, Row II. and Shandon lying close together. At the three minima the Garelochhead curve is almost the same as the others, but it shows a tendency to rise and fall more rapidly, thus having a slightly longer warm and cold season, and slightly shorter transition seasons than the other stations.

It is interesting to observe that the difference in mean temperature of the vertical section between the different stations is greatest at the Autumnal maximum, and least (practically imperceptible) at the Spring minimum.

The range of temperature between surface and bottom layers, as would be expected from the depth, is considerably less than for Shandon; but the dates of change from positive to negative slope are practically the same, coinciding with the seasonal maximum and minimum, the former in September, the latter in March.

Temperature Sections of Gareloch.—Temperature sections were drawn for each trip, and are reproduced in Plate XVI., figs. I. to XVII.

Section I., April 13th, 1886.—The weather was practically dead calm, anticyclonic, with air-temperature below the average of the month. Observations were made at all stations, the average temperature of the loch being 41°·8, and of the superficial 5 fathoms 42°·7. The isotherm of 42° was at 6 fathoms at Row I., 4 fathoms at Row II., and at $2\frac{1}{2}$ fathoms at Garelochhead. The other isotherms ran fairly parallel, and especially in the seaward half of the loch showed a marked dip toward the mouth, such as suggests an upwelling of colder deep layers about Shandon, or a less rapid heating of the water just inside the bar. The upper half of the loch showed practically horizontal isotherms indicating a tranquil condition. The observations were all made nearly at low tide.

Section II., April 21st, 1886.—Observations being made only at Shandon and Garelochhead, this section is confined to the upper half of the loch. The weather up to the 18th had been calm, on the 19th there was a north-easterly breeze, on the 20th an E.N.E. gale, and on the 21st there was a breeze from north-east blowing obliquely down the loch. Great temperature disturbances had taken place. The mean vertical temperature at Shandon had risen from 41°·4 to 42°·0, that at Garelochhead from 41°·6 to 43°·0. The great mass of the water was close to 42°, but varied irregularly. At Shandon the isotherms from 44°·5 to 42° were crowded into the superficial $1\frac{1}{2}$ fathoms; at the head those from 45° to 42° were spread through the upper 5 fathoms. There thus appeared to be a distinct heading up of warm surface water, the isotherms all dipping to the head of the loch, where the surface water had been considerably freshened. The state of matters was such as could be readily explained by the action of a southerly wind, but the wind had blown only from the north-east since the calm. It is, of course, possible that the easterly component drove estuary water into the Gareloch, but this does not seem to be the case; and the section stands an interesting exception to the usual action of the wind. The result is very probably due to deep tidal effects; observations were made nearly at high-water. The intermediate minimum of temperature is too slight to be profitably discussed.

Section III., June 16th, 1886.—Here warming had gone on rapidly, the mean temperature of the loch being 48°·1, and of the superficial 5 fathoms 48°·5. The water was well stratified, the isotherms dipping strongly toward the mouth, and the bar seemed to have no effect on them. The isotherm of 48° was at a depth of 15 fathoms at Row II., 9 fathoms at Shandon, and only $2\frac{1}{2}$ fathoms at Garelochhead. The higher isotherms were farther apart than the lower, showing a more thorough equalisation of temperature, contrary to what would be expected during warming-up. An anticyclone had prevailed from June 1st to 9th, followed by a cyclone, which on the 16th caused a stiff breeze from

a point or two north of west. This showed the full action of the northerly component, and taken in conjunction with the conditions of Section II., suggested that in the Gareloch an east wind acts as if it blew *up*, a west wind as if it blew *down*.

The tide throughout was in the first quarter of ebb, and thus, as in the previous case, the disturbance of the strata was probably in large measure tidal.

Section IV., August 3rd, 4th, 1886.—The average temperature of the loch was 52°·9, and of the superficial 5 fathoms 53°·1. The two landward stations were observed on August 3rd, with the tide about half ebb, and showed nearly uniform temperature, with nearly horizontal isotherms having a slight seaward dip. The two seaward stations observed on the 4th, just after low-water, showed strong landward dip of the isotherms, and the bar showed a very marked effect of separating the colder water outside from the warmer within. Thus at Row I. the temperature was 52°·1 at the surface, and 51°·3 at the bottom; at Row II. it was 53°·3 at the surface, 52°·2 at the bottom. Between Row II. and Shandon the isotherms dipped gently landward.

The wind was variable, on account of the rapid passage of small cyclones; on the 3rd there was a light westerly wind, and on the 4th a light south-easterly, which would partly account for the steep dip of isotherms at the mouth.

Section V., September 24th, 1886.—The tide was in the first quarter of ebb, and the section shows at Shandon an exceptionally well-marked intermediate maximum, the traces of which are distinctly seen at Garelochhead. It is unfortunate that the observation at Row II. was omitted on this trip, but there are indications that the intermediate maximum did not extend so far. From September 10th to 22nd an anticyclone had kept up light variable breezes; the 24th, when the observation was made, was dead calm. The salinity conditions were somewhat peculiar, the water at the head on the surface being salter than at either of the other stations; that at Shandon was freshest. The average temperature of the loch was 53°·9.

Here the surface water, cooling rapidly, seems to have floated on the warmer layers below, which preserved the natural summer distribution of cooling downward to the bottom.

A similar though less marked distribution of temperature occurred a year later. See Section XIII.

Section VI., November 11th, 1886.—The average temperature was 50°, that of the upper 5 fathoms 49°·5. The distribution was comparatively simple, cooling being in progress from the surface downward. But there was a distinct trace of an intermediate maximum at Shandon, lying very much nearer the bottom than in Section V. There was a general gentle dip of the isotherms seaward from Garelochhead to Row II., but a sharp dip landward from Row I. to Row II., the result being that at Row II. the cold layer was thicker than anywhere else. This may partly be accounted for by the fact that the Row stations were observed about half-an-hour before and the others about half-an-hour after high-water. The tidal streams about high-water are, however, relatively feeble.

Garelochhead had the saltest, Row I. the freshest surface water in the basin, a result probably due to the flood-tide carrying in brackish estuary water. The weather was dead calm. There had been strong south-westerly winds from the 1st to the 4th, and after that date very disturbed weather.

Section VII., December 28th, 1886.—Mean temperature of loch 44°·2, of superficial five fathoms 43°·2. The cold surface layer was thinnest, but with greatest range of temperature at Garelochhead. The isotherms of the surface 3 fathoms dipped gently landward, below that level gently seaward. The tide was close to high-water. The wind was blowing a gale from the north-west and west, in a general way down the loch, but the tide appears to have more than neutralised its effect in disturbing the layers of water except, curiously enough, at the mouth.

The warmest water inside the bar was 45°·1 on the bottom, that outside was 46°·0 on the bottom, where the depth was only half as great as inside.

Section VIII., February 12th, 1887.—The mean temperature of the mass was 42°·8. The isotherm of 42°·5 ran horizontally at 2 fathoms; the others (43° and 43°·5 alone appeared) dipping very gently seaward. The tide was in the second quarter of flood, and the weather was anticyclonic on the 12th, with a light south-easterly breeze. A remarkably uniform distribution of temperature prevailed, showing the winter cooling of the basin practically completed.

Section IX., March 25th, 1887.—The temperature of the mass of water was 43°·0, almost the same as for Section VIII., but the upper 5 fathoms had become somewhat warmer. The range of temperature being less than half a degree, it is impossible to draw any conclusions regarding circulation from this section. A north-westerly gale was blowing while the observations were taken, and the tide was in the first quarter of ebb, hence there was a strong current setting out.

Section X., May 6th, 1887.—The mean temperature of the section was 46°·0, and that of the upper 5 fathoms, 46°·7, showing progressive heating, especially in the upper layers, and toward the head of the loch. The line of 46° ran from the sill of the bar (5 fathoms) to 2½ fathoms at the head. It so happened that a partial observation was made off Clynder, which showed that the isotherms of the upper 2 fathoms dipped thence landward to the head, while those from 2 to 5 fathoms dipped seaward; but from Clynder to Row II. the dip was landward throughout, thus showing a considerable upwelling on the bar. The tidal phase was low-water at Shandon, and the beginning of flood at Row. The wind was south-east, and light. The surface water warmed up very rapidly from Row to the head. The appearance was that of an upwelling of colder water at Row, combined with strong sun-heating, and perhaps slight accumulation of surface water at the Garelochhead.

Section XI., June 13th, 1887.—Rapid warming had gone on from the surface, the mass-temperature being now 50°·7, and the upper 5 fathoms 51°·4. Stratification was distinct, the isotherms below 5 fathoms dipping gently seaward, and above that level showing an accumulation of warmer surface water about Shandon, and of cooler water

about Row, indicating cold upwelling at the latter place. The most rapid change of temperature with depth occurred (at Shandon) from 15 to 20 fathoms, where there was a marked crowding of the isotherms. The tide was at the last quarter of ebb, and a very light south-westerly breeze was blowing, the conditions being anticyclonic.

Section XII., August 6th, 1887.—This section represents the loch at the maximum temperature ever found, and nearly at the greatest range of vertical temperature. The mean was 57°·9, and of the upper 5 fathoms 58°·5. The isotherms dipped steadily landward, and showed a nearly vertical arrangement at the bar, which separates water of markedly different temperature. The loch was stratified into a thin top layer of water very warm on the surface, a thick well-mixed intermediate stratum, and a thinner bottom layer at Shandon of rapidly diminishing temperature. It is noteworthy that the water from 57° to 54°·4 at Shandon was quite cut off by bottom water over 57°·4 from the cooler water outside the bar. Altogether this section is a characteristic example of great surface heating. The weather was calm, and the tide at half flood, the latter probably accounting for the landward dip of the isotherms.

Section XIII., September 30th, 1887.—Average temperature, 54°·0, and of upper layer of 5 fathoms 53°·9. An excellent example of surface cooling, leaving the great mass of water over 54°, with a thin surface zone and a thinner bottom zone (at the ends of the loch only) slightly cooler. The range of temperature is too slight to discuss movements, the whole mass of water being fairly well mixed.

Section XIV., November 29th, 1887.—The mass-temperature had now become 46°·1 (the surface layer of five fathoms being 45°·6). The section showed rapid cooling in progress. The upper layer, colder than 46°, was compressed within two fathoms at Shandon, and 1 fathom at Row I., but expanded to 5 fathoms at Row II., and 8 fathoms at the head. This seems to indicate upwelling at Shandon, and down-sinking at Row and Garelochhead, the Row bar keeping out the warmer deep water.

There was a very light north-easterly breeze, and the tide was in the last half of flood.

Section XV., February 9th, 1888.—The mean temperature of the section was 43°·7, and that of the surface layer 43°·5, very similar to the conditions shown in Section VII. The temperature was practically uniform, and the two isotherms which appear run parallel to the configuration of the basin, *i.e.*, they indicate a slight upwelling at both ends. The wind was N.W., nearly down loch, and the tide in the last quarter of flood, or setting up loch; the former would perhaps account for the slight upwelling at the head, the latter for that at the mouth.

Section XVI., March 28th, 1888.—The mean temperature was 41°·9, practically the same as in Section I. The tidal phase was low-water, and a strong north-east wind blew. Homothermic conditions prevailed throughout, showing thorough mixture. The total range of temperature was in fact only 0°·3, the surface being coolest.

Section XVII., June 7th, 1888.—Gradual warming from above here appears. The mass-temperature had reached 46°·7, and the isotherms steadily dipped landward. An unusual lapse of time separated the observations at Garelochhead and at Row, the tide

being $\frac{3}{4}$ hours ebb at the former, and $4\frac{1}{4}$ hours ebb at the latter. A strong east wind was blowing, leading to well marked banking up of warm surface-water against the eastern side (see p. 106). The cross-section shows that the rise of surface isotherms in the longitudinal section at Clynder is due to the colder water drawn up on the windward side and driven across the loch. The same thing probably happened, though perhaps in a less degree, elsewhere. The mass of relatively cold water which stretched along the bottom from the lip of the barrier diagonally to beyond Shandon is exaggerated in the section by the dividing isotherm happening to be one at which the colour is changed, the temperature below 46° (or even 46°·5) being practically uniform to the bottom.

Section XVIII., August 20th, 1888.—There were only two sets of soundings, but these showed for the head of the loch the greatest range of vertical temperature ever observed in summer. Below 54° at 5 fathoms the isotherms were practically parallel and horizontal. Above that level they dipped landward, the water on the surface rapidly growing warmer to Garelochhead. The weather was calm, and the tide rather more than half ebb.

Section XIX., September 6th, 1888.—The average mass-temperature was 54°·1, and that of the upper 5 fathoms 54°·7. The isotherms showed a very slight dip landward at the head, and a very slight dip seaward at the mouth, except between Row I. and II. The section seems to show the commencement of seasonal cooling. A strong, squally S.W. to W.S.W. wind was blowing, and the tide was about quarter ebb.

The three Sections for June are representative of the conditions of rapid heating.

In June 1886 there was the most perfect instance of parallel isotherms dipping seaward, each of the three isotherms of which more than two points were fixed being almost straight lines. The strata of water seemed in fact to be uniformly displaced or tilted so as to bring up the cold lower layers against the head-slope, and to bring down the warm upper layers on the barrier.

In June 1887, with higher temperature and greater range, the isotherms were also remarkably straight and parallel, dipping seaward, but more gently than in 1886. The upper isotherms were somewhat irregular.

In June 1888 the isotherms present on the whole the best example of landward dip, the only other instance at all well marked of an accumulation of surface water at the head being in Sections XII. and XIV., August and November 1887—both cases of flood-tide.

All the June observations were made during the first half of ebb; and the great range of temperature makes them particularly useful for the purpose of detecting evidence of the circulation of water by means of the direction of isotherms.

The phenomena associated with the Bar off Row Point are well brought out in several of the sections. Out of the whole number of 19, there are 13 sections in which observations were made at Row I. and at Row II., on both sides of the shallow bar which separates the Gareloch from the Estuary. In six of the cases the isotherms (with

one exception at flood-tide) dip landward from Row I. to II.; in six of the cases (with practically only one exception at ebb-tide) they dipped seaward from Row II. to I.; and one case was indeterminate. The indeterminate case was Section XVI., the observations being made at low-water, when the whole mass of water was within 0°·2 of 42°.

The six instances of landward-dipping isotherms were observed in February 1888, August 1886, August 1887, September 1888, November 1886, and November 1887. They are thus all cases in which the water, as a whole, was at a maximum or cooling. The February instance is peculiar in showing a minimum temperature in the middle depths inside the loch, and in having too few isotherms to justify discussion. It may accordingly be passed over. The September Section, No. XIX., is also exceptional, as it shows a maximum temperature in the middle layers outside the bar, and it is also the only one in which this form of dip occurs with an ebb-tide. It shows the uprising and outflowing of water between 54° and 55° over the bar, but at the time the wind was blowing strongly against the tide, and there are signs of this action driving in rather cooler surface water, and compelling the ebb-tide to escape as an undercurrent. Distinct traces of banking up by wind at the head of the loch are shown. The remaining four cases may be taken as typical. In both the August cases the tide at Row was in the first quarter of flood, in one case (No. IV.) with a wind blowing into the loch, in the other (No. XII.) it was calm. In both, colder water is entering, and in both the bar seems to stop the deeper and colder layers outside from getting in. In fact the surface temperature at Row I. is found (judging by the isotherms) on the sill of the bar; the horizontal stratum in line with the bar being 0°·5 in one case and 1°·5 in the other *colder* at Row I. than on the bar. The two November sections show a substantially similar state of matters, except that the water entering was then warmer than that inside, but it entered in the same way, affecting most the surface about Row II.

If we may look on the isotherms as representing originally-horizontal planes between layers of water of different temperature, and suppose that these layers do not change in temperature, the inflection of the isotherms indicates that the water from outside pushes against and bends up those layers, driving the bent-up portions back into the loch on the surface, and so thickening them at the lines of inflection. In other words, it proves that the tide is mainly a mass movement, bringing up the outer water—warmer or colder according to the season—against the inner waters, pushing the latter forward bodily, not slipping under and lifting them up, as is the case in a tidal river. The bar effectually prevents mixture below its level, and also prevents the mere slipping to and fro of a mass of water cut off horizontally above. It acts like the continental edge on oceanic isotherms, causing a disturbance in the distribution of the water to a considerable depth, and forcing up the deep layers to the surface, so that in these conditions of flood-tide Row I. has the deep temperature raised much nearer the surface than Row II., showing strong upwelling.

It is unfortunate that observations were not made on the shallowest point of

the bar, where, in all probability, the isotherms would be found still nearer the surface than at Row I., and the slope to Row II. would be proportionally intensified.

The six cases of seaward-sloping isotherms occurred in March 1887, April 1886, May 1887, June 1886, June 1887, and December 1886. Thus all with one exception occurred during the process of warming up, and all with the same exception at ebb-tide or at low-water. This exceptional case was the only one in which an intermediate minimum temperature was observed. It occurred during a down-loch gale, which might have accelerated ebb-tide, as the Row observations were made just before high-water. The Section for March must also be passed by, as the whole water, inside and outside, was practically at uniform temperature. No. I., April 1886, was observed at $\frac{1}{2}$ hour flood, and while the lower isotherms dipped seaward, the upper dipped landward. The weather was calm. Here we observe the upper layer of warmer water steadily thickening toward and beyond the mouth of the loch as the flood-tide was beginning to enter. The May section, at low-water, shows the isotherms practically horizontal across the bar. The section for June 1886 also shows the bar as producing no apparent effect on a down-loch wind distribution; and the section for June 1887 shows only a slight dip.

It is unfortunate that practically all the warming-up sections should have been observed with an ebb-tide, and all the cooling-down sections with a flood-tide; but a consideration of the diagrams makes it seem likely that it is a tidal rather than a seasonal effect which brings out the typical forms of isothermal dip in the case of the Gareloch. On the other hand, it may be that all we can safely say is: During the months of maximum temperature and of rapid cooling the contrast of temperature between the water inside and outside the Gareloch is much greater than it is during the months of minimum temperature and of rapid warming.

Mean Temperature of Gareloch.—The mean temperature of the mass of water in the Gareloch was calculated in two different ways. As the depression is of comparatively uniform depth, and the several stations rarely differ much in mean temperature, it seemed reasonable to take the average of the vertical temperature means as that of the whole section. This is done in Table XLIII., cases where one or more observations were omitted being supplied by a probable value. The last column of this table gives the mean temperature calculated from the temperature sections by measuring the areas between adjacent isotherms and making allowance for the volumes of the 10-fathom slices of water. The temperature of the upper slice of 10 fathoms being a, and that of the lower b, the mean temperature was calculated by the formula $T = \frac{3{\cdot}7a + b}{4{\cdot}7}$. Details of this measurement are given in Table XLIV. It is remarkable how closely the two estimates correspond, the mean of the nineteen temperature trips being identical when estimated in either way. The greatest deviations were 0°·5 in August 1886, 0°·6 in August 1887, and 0°·4 in November 1887.

TABLE XLIII.—*Mean Temperature of Vertical Soundings, Gareloch.*

Trip.	Date.	Row I.	Row II.	Shandon.	Head.	Mean.	Mean from Section.
I.	13th April 1886,	42·3	41·8	41·4	41·6	41·8	41·77
II.	21st „ „	42·8	42·3	42·0	43·0	42·5	...
III.	16th June „	48·7	48·3	47·6	47·9	48·1	48·07
IV.	3rd August „	...	...	52·9	53·1	52·5	52·96
	4th „ „	51·6	52·6	...	...		
V.	24th September „	53·1	54·0	54·4	53·9	53·8	53·96
VI.	11th November „	50·2	49·4	50·5	50·1	50·0	50·03
VII.	28th December „	44·0	44·4	44·4	43·8	44·1	44·24
VIII.	12th February 1887,	43·1	42·9	43·1	42·9	43·0	42·85
IX.	25th March „	43·0	42·9	42·9	43·0	43·0	43·00
X.	6th May „	46·1	45·9	45·7	46·4	46·0	46·00
XI.	13th June „	51·0	50·6	50·4	51·0	50·7	50·75
XII.	6th August „	55·8	57·6	57·4	58·5	57·3	57·92
XIII.	30th September „	54·0	53·9	54·1	54·4	54·1	54·02
XIV.	29th November „	47·7	46·6	46·8	44·9	46·5	46·09
XV.	9th February 1888,	44·5	44·0	43·8	43·6	44·0	43·70
XVI.	28th March „	41·8	41·9	42·0	41·7	41·9	41·91
XVII.	7th June „	46·5	46·3	46·5	47·7	46·7	46·72
XVIII.	20th August „	52·6	53·0	52·8	55·7	53·5	...
XIX.	6th September „	53·7	54·1	53·6	54·9	54·1	54·15
	Mean, . .	48·0	48·0	48·0	48·3	48·1	48·11

TABLE XLIV.—*Mean Temperature at Various Depths in the Gareloch.*

Trip.	Date.	Days since last Trip.	Mean Temp. Weighted	Diff. from last Trip.	Change per day.	Temp. 0–10 fms.	Change per day, 0–10 fms.	Temp. 10–20 fms.	Change per day, 10–20 fms.
I.	13.4.86	...	41·77	...	...	42·00	...	40·95	...
III.	16.6.86	64	48·07	+6·30	+0·098	48·23	+0·097	47·46	+0·102
IV.	3.8.86	48	52·96	+4·89	+0·102	53·05	+0·100	52·64	+0·108
V.	24.9.86	52	53·96	+1·00	+0·020	54·06	+0·020	53·58	+0·018
VI.	11.11.86	48	50·03	+3·93	−0·082	49·78	−0·089	50·96	−0·055
VII.	28.12.86	47	44·24	−5·79	−0·123	44·04	−0·122	44·96	−0·128
VIII.	12.2.87	46	42·85	−1·39	−0·030	42·71	−0·029	43·35	−0·035
IX.	25.3.87	41	43·00	+0·15	+0·004	43·00	+0·007	43·00	−0·001
X.	6.5.87	42	46·00	+3·00	+0·071	46·20	+0·076	45·25	+0·054
XI.	13.6.87	30	50·75	+3·75	+0·125	51·00	+0·160	49·82	+0·152
XII.	6.8.87	62	57·92	+7·17	+0·116	58·16	+0·115	57·02	+0·116
XIII.	30.9.87	55	54·02	−3·90	−0·071	54·02	−0·075	54·00	−0·055
XIV.	29.11.87	60	46·09	−7·93	−0·132	45·81	−0·137	47·14	−0·114
XV.	9.2.88	72	43·70	−2·39	−0·033	43·65	−0·030	43·87	−0·045
XVI.	28.3.88	47	41·91	−1·79	−0·038	41·89	−0·037	42·00	−0·040
XVII.	7.6.88	72	46·72	+4·81	+0·067	46·90	+0·070	46·07	+0·057
XIX.	6.9.88	91	54·15	+7·43	+0·082	54·37	+0·083	53·33	+0·080

As these tables show, the loch was in an almost perfectly homothermic state at the period of annual minimum in March or April, and returned to a similar condition in September or October, just after the annual maximum. At other times there was a considerable range of temperature between surface and bottom, and also between the mean vertical temperatures at the various stations, the range from one to another being 1° or 2°. The change of temperature between contiguous stations seems to be due as much to the influence of wind as to that of season.

In order to allow an exact comparison to be made with the other natural divisions, the temperature of the surface layer 5 fathoms deep was calculated, and the result is expressed together with the mean in the curves of fig. 47, Plate XXXI., on which the average monthly temperature of the air at Helensburgh is also shown. For the whole period under observation the average temperature of the superficial slice of water was identical with that of the mass, being a fraction of a degree higher during the season of heating, and a fraction of a degree lower during the season of cooling. The two curves coincided at the annual maximum and minimum. It is consequently sufficient to consider the variations of the temperature of the mass as a whole.

Starting from the minimum of 41°·6 on about April 15th, 1886 (about half a degree lower than that of any of the other divisions), the Gareloch reached its maximum of 54°·1 on September 15th, a gain of 12°·5 in 153 days, or at the average rate of 0°·081 per day. The period and amount of heating were practically identical with those of the Channel, and the rate of gain of temperature was twice that of Loch Fyne. The minimum of 42°·5 was reached on February 28th, 1887, indicating the loss of 11°·6 in 166 days, the rate being 0°·070 per day. Here again the rate of change of temperature was twice that in Loch Fyne, and slightly greater than in the Channel. The next maximum, 58°·0, occurred on July 23rd, the duration of heating being only 145 days, more than a month less than the time of heating at any other place. The rise of temperature was 15°·5, and the average rate of heating as much as 0°·107 per day, being the greatest observed in any mass of water in the Area. The shallow Gareloch, on this occasion, was naturally enough the division to respond most rapidly to the exceptional solar radiation of 1887. The following fall of temperature was prolonged until March 31st, 1888, when it reached a minimum of 41°·9 after 251 days, the longest period of cooling recorded in any division. The total loss of temperature was 16°·1, and the rate of cooling 0°·064 per day, the same as the rate in the Channel. The last maximum observed probably occurred on September 15th, and reached 54°·8, a gain of 12°·9 in 168 days, again the shortest period of heating in the Area. The rate of heating was 0°·079 per day.

Table XLV. gives concisely the comparative statistics of heating and cooling in the four typical divisions of the Area and in Loch Goil.

The mean duration of heating for the Gareloch, as a whole for the three years observed, was 162 days, and for the two periods of cooling 208 days. Taking into account the two years for which comparable observations exist, the ratio of the time of heating to that of cooling was 160 to 208 days, or 100 : 130. This may be compared

with 100 : 115 in the Channel, 100 : 100 in the Arran Basin, and 100 : 91 in Loch Fyne, and shows that shallowness and exposure to land influences tend to increase the rapidity of heating, and probably to retard cooling. The cooling of 1887–88 was evidently anomalous, but it may only exaggerate what seems to be a normal disparity.

The mean rate of change of temperature per day, calculated from the figures in Table XLIV., is 0°·074 for the whole mass of water, a change of temperature of 1° requiring on the average 13½ days to be effected. The bottom layer of 10 fathoms (10–20 fathoms

TABLE XLV.—*Period of Heating and Cooling, and Daily Rate of Change of Temperature in the Clyde Sea Area.*

Division.	Warming, 1886.	Rate per day.	Cooling, 1886.	Rate per day.	Warming, 1887.	Rate per day.	Cooling, 1887.	Rate per day.	Warming, 1888.	Rate per day.
Channel, . . .	147 days	0°·090	171 days	0°·065	189 days	0°·065	217 days	0°·062	...	...
Arran Basin, . .	165 ,,	0°·058	151 ,,	0°·053	186 ,,	0°·046	199 ,,	0°·049	...	...
Loch Fyne, . .	168 ,,	0°·047	156 ,,	0°·039	206 ,,	0°·037	184 ,,	0°·045	170 days	0°·038
Gareloch, . . .	153 ,,	0°·081	166 ,,	0°·070	145 ,,	0°·107	251 ,,	0°·064	168 ,,	0°·07[illegible]
Loch Goil, . . .	198 ,,	0°·038	144 ,,	0°·040	160 ,,	0°·058	210 ,,	0°·046	180 ,,	0°·043

in depth) changed its temperature at the average rate of 0°·072 per day, or 1° in 14 days. The curve of variation in the rate of change of water-temperature with time which is not reproduced brings out the peculiarly prolonged period of falling temperature in the spring of 1888.

The relation of air-temperature to water-temperature is also shown in fig. 46, where it is seen that the air-curve cuts the water-curve at the maximum in descending, and rather after the minimum in ascending. This proves, as in the case of Loch Fyne, that contact with air colder than the surface water arrests the process of heating by radiation after the autumnal equinox, while radiation seems to check the loss of heat even in contact with colder air after the vernal equinox. It is also remarkable that the maximum rate of water-heating occurs nearly a month before the maximum air-temperature is reached, while similarly the most rapid cooling occurs a month or so before the minimum of air-temperature. This shows that radiation and the other influences which produce changes of air-temperature produce the changes of water-temperature not consequently but simultaneously, if not previously.

The air-temperature at Helensburgh (considering monthly means) was above the mean temperature of the water of the Gareloch for 154 days in 1886, for 94 days in 1887, and for 155 days in 1888. The air was colder than the water for 245 days in 1886–87, and for 250 days in 1887–88. Speaking generally, this gives the air warmer than the water for four and a half months from April to August, and colder for the remaining seven and a half months. For the two complete seasons included in the years

1886–88, the average period of air warmer than water was for the divisions Channel, Arran Basin, Loch Fyne, and Gareloch, 134, 136, 143, and 124 days; while for air colder than water the figures were 237, 223, 219, and 248 days. The rapid heating of the Gareloch by radiation brings up the water-temperature so near the air-temperature that a short time of air-cooling equalises the two, and stops further heating in the water.

Interpolating, as in previous cases, probable values for the first three months of 1886 and the last three of 1888, we get from fig. 47 the data for comparing the mean annual temperature of water and air.

TABLE XLVI.—*Mean Annual Temperature of Air and Water for the Gareloch.*

Year.	I. Air (Mean for Area).	II. Air (Helensburgh).	III. Water (Mass).	IV. Water (0–5 Fathoms).	Difference (Air II. and Water III.).	Difference (Air I. and Water III.).
1886	46°·2	46°·5	47°·4	47°·5	− 0°·9	− 1°·2
1887	47°·0	45°·9	48°·7	48°·7	− 2°·8	− 1°·7
1888	46°·7	47°·3	47°·5	47°·6	− 0°·2	− 0°·8
Mean	46°·63	46°·57	47°·87	47°·93	− 1°·30	− 1°·23

The mean temperature of the air at Helensburgh for 1887 is doubtful, as three months had to be interpolated. The early spring of that year was exceptionally cold at Helensburgh compared with the other Clyde stations, hence the low annual average. The mean, as calculated for the difference between the water and local air, or general air-temperature, is practically the same, so that one has some confidence in saying that the mass of water in the Gareloch (which is practically at the same temperature as the superficial layer) is a degree and a quarter warmer than the air, a somewhat greater excess than in the case of the surface water of Loch Fyne. Taking the average of the years 1886 and 1887, so as to be comparable throughout, the surface 5 fathoms of water in the various divisions were warmer than the air to the following amounts:—Channel, 1°·7; Arran Basin, 1°·7; Loch Fyne, 1°·5; Gareloch, 1°·9 (or, taking general air-temperature, 1°·5). The variation is so slight as to be negligable, and we are justified in saying that for these two years the surface layer of 5 fathoms of water in the Clyde Sea Area was 1°·6 warmer than the overlying air. Considering the mass of water, and not the surface layer, we find the Channel and Gareloch practically the same, an excess of 1°·7, while the excess of the Arran Basin is only 0°·35, and of Loch Fyne 0°·45.

LOCH GOIL.

The physical features of Loch Goil are described in Part I., p. 647. The name is applied to the water surface lying within a bar rising to 7 fathoms, which marks off Loch

Goil from the Dunoon Basin (Lower Loch Long) at the point where Upper Loch Long begins. Its length is 5 miles, and average width under $\frac{3}{4}$ mile. The whole area of the water is 3·4 square miles, and the land drainage is relatively large, being 34 square miles. The ratio of water to total drainage area is 1 : 11·07, the smallest ratio for any of the sea-lochs, except the Holy Loch, which is simply a bay receiving the drainage of Loch Eck, a fresh-water lake. The volume of Loch Goil is 0·037 cubic sea miles, and the tidal increment 0·004. Its mean axial depth is $30\frac{1}{2}$ fathoms, and average depth over all, 14 fathoms.

The probable volume of rainfall reaching the loch in an average year is estimated at 0·02601 cubic sea miles. In 1886–87 it was about 0·01618.

The average percentage of pure sea-water in the loch is . . .	92·3
The maximum (in August 1886) was	94·8
And the minimum (in February 1887)	86·7

Loch Goil challenges special contrast with the Gareloch, being similar in orientation, indeed it is a continuation of the Gareloch in direction; but the axis is curved instead of straight, thus presenting a more complicated outline to up-and-down winds. The axis is the same length as that of the Gareloch, the bar is similarly situated and of equal depth in both, and the slopes at the head of the lochs have the same angle, but Loch Goil is twice as deep as the Gareloch. The surrounding hills are much higher, the relative drainage area very much greater, and the normal annual inflow of rain water much greater also. In fact, Loch Goil appears to receive its own volume of rain water on the average in seventeen months, the Gareloch in thirty-six months. In spite of this Loch Goil remains much salter than the Gareloch, hence there must be a more rapid escape of fresh water, or a better supply of salt, the latter being most likely, as the very deep water of the head of the Dunoon Basin lies immediately outside the bar.

The particular points of contrast are thus depth, enclosure by mountains, greater salinity, and greater volume of fresh water passing through.

Comparison must also be made with Loch Fyne, to the Upper Basin of which Loch Goil is, on a small scale, very similar, the station at Stuckbeg strikingly resembling that at Strachur. Loch Fyne, however, requires in normal years forty-five months in order to receive its own volume of fresh water, its drainage area being relatively small.

Consideration of Loch Goil involves reference to the conditions at the Dog Rock station of Dunoon Basin.

Observations at Dog Rock, Dunoon Basin.—The position of observing was at the head of the Dunoon Basin, with Dog Rock bearing N.N.E. 4 cables. The depth is 50 fathoms, this being the greatest depression of the Dunoon Basin, except that off Gantock. To the north-east the water shoals to the sill of Loch Long, to the west it shoals to the more pronounced sill of Loch Goil, to the south it shallows gradually. See Section 16D., Plate 9 in Part I. The density of the water at this station was as follows :—

	Surface.		Bottom.
Mean (11 observations), . .	1·02280	...	1·02463
Maximum, ...	1·02416	...	1·02504
Minimum, ...	1·01867	...	1·02420

The average percentage of pure salt water at the surface was 84·1, at the bottom 94·5, in the whole vertical section 92·8; and the assumed percentage for a normal year in the vertical section is 92·5, practically the same as that in Loch Goil, as a whole, and 1 per cent. less than in the Dunoon Basin as a whole.

TABLE XLVII.—*Temperature Observations off Dog Rock.*

No. . .	1	2	3	4	5	6	7	8	9	10
Date . .	13.4.86	17.6.86	5.8.86	24.9.86	11.11.86	12.11.86	22.12.86	8.2.87	25.3.87	7.5.87
No. of Points .	5	10	13	16	7	6	8	9	6	9
Temp. . .	41·8	43·9	47·3	51·9	51·2	51·4	47·4	44·4	43·5	44·4
Slope . .	+1·9	+5·1	+3·5	+0·2	−1·7	−2·2	−2·1	−2·8	−0·7	+3·7

No. . .	11	12	13	14	15	16	17	18	19	...
Date . .	14.6.87	7.8.87	29.9.87	15.10.87	30.11.87	9.2.88	1.3.88	28.3.88	3.9.88	...
No. of Points .	13	9	6	6	9	6	6	6	9	...
Temp. . .	46·9	51·7	53·3	52·6	49·0	44·9	44·1	42·7	50·3	...
Slope . .	+6·8	+8·3	+0·4	−0·3	−2·6	−0·8	−1·1	+0·3	+6·9	...

The highest mean vertical temperature observed was 53°·3 in September 1887, the lowest was 41°·8 in April 1886, a total range of 11°·5. The form of the individual curves was often interesting. Nos. 4, 13, 14, and 18 were, in view of their "slope," practically homothermic. This was really the case only for Nos. 13 and 18 in September 1887 and March 1888, the former the yearly maximum, the latter the yearly minimum. In the case of No. 14, and very conspicuously in No. 4, the vertical curve was made up of sections of alternately positive and negative slope giving a contorted curve about a vertical axis, showing the existence of alternate layers of unmixed warmer and colder water (see L in fig. 3, Plate XXII.). Curve 4, in a depth of 50 fathoms, was very fully delineated, sixteen points being determined on it. It showed that the layers alternated, in increasing thickness, warm, cool, warm, cool, and warm again. The surface temperature was 52°·9 (the maximum), the bottom 52°·1; the minimum, at 29 fathoms, was 51°·1, and the average of the whole depth 51°·9.

Nos. 1, 2, and 10 were typical positive paraboloid curves, showing a great range in the surface layers and practical homothermicity below. No. 3 is a positive curve showing rapid heating from the surface to 10 fathoms, and beneath that a negative curve of nearly uniform gradient to the bottom.

The negative curves here, as in all other stations, are very much less pronounced than the positive, the best defined negative paraboloid being No. 15. No. 8 shows a disturbance on a negative parabolic curve somewhat more complex than No. 3 for a positive, but of the same kind. In both the inflection occurs at 10 fathoms, suggesting the action on the surface of outflowing water from Loch Goil.

Curves 5 and 6 were taken on consecutive days, November 11th and 12th, 1886, and the average temperature on the second day seemed to be about 0°·2 higher than on the first, although the curves betoken surface cooling. This is partly accounted for by the second observation being made in a spot 5 fathoms deeper than the first, these 5 fathoms being occupied by warmer water. Both curves show a sub-surface maximum, followed by a fall of temperature, and if more points on the curves had been ascertained they might show a closer concordance.

Out of the nineteen curves it is interesting to notice that no less than nine show mixed slopes to a greater or less extent; but from this station alone it does not appear that change of slope within the curve is a normal feature of seasonal range. The position of the Dog Rock Station is unique in the Area, as it is a deep depression at the junction of three long narrow channels of different depth, salinity, and accessibility to sea water. Consequently, it is peculiarly subject to variations in the slope of its temperature curve similar to those at Otter I. Kilfinan.

Observations at Loch Goil Mouth.—The observations made at the mouth of Loch Goil were intended to be on the deepest part of the sill or bar which separates it from the Dunoon Basin. The depth of observation usually varied from 9 to 12 fathoms, although it is probable that a line, with 8 fathoms as its maximum depth, runs across the mouth of the loch. The crest of the sill is narrow, and no leading marks were found to enable its position to be fixed exactly while observing. The station lay on the line between the curve of Corryn on the chart and Swine's Hole, where the channel was $\frac{1}{3}$ of a mile wide.

No salinity observations were made.

TABLE XLVIII.—*Temperature Observations at Loch Goil Mouth.*

No.	1	2	3	4	5	6	7	8	9
Date	5.8.86	8.2.87	25.3.87	7.5.87	14.6.87	7.8.87	29.9.87	30.11.87	10.2.88
No. of Points	4	3	3	6	6	3	2	6	3
Temperature	49·4	43·5	42·8	46·5	49·4	55·9	53·4	47·3	45·0
Slope	+3·3	−2·8	−0·8	+2·4	+2·5	+2·8	+0·3	−2·3	−0·2

The curves were, as a rule, nearly straight lines, occasionally showing very well-marked positive or negative slope.

Observations off Carrick Castle.—Observations were made twice off Carrick Castle, $\frac{2}{3}$ of a mile distant from the station at the mouth of the loch, in a depth of 25 fathoms. No

salinity observations were made. They were on March 25th and September 29th, 1887. Six points on the curve were fixed on each occasion. On the former the mean temperature was 43°·6, and the slope −1°·6; on the latter the mean temperature was 51°·3, and the slope +4°·5. Both curves are S-shaped, one positive and one negative. They betoken a division of the water into three layers, a surface and a bottom one of nearly uniform temperature, and an intermediate zone of rapid change of temperature.

Observations at Stuckbeg.—At this point observations were made at the deepest part of Loch Goil in mid-channel, about two-thirds of the way from the mouth to the head of the loch. The depth is 47 fathoms, and the bed of the loch is exceptionally steep (see Section 8B., Plate 7 in Part I.). The density of the water was as follows:—

	Surface.		Bottom.
Mean (10 observations), . .	1·02293	...	1·02452
Maximum, ...	1·02441	...	1·02471
Minimum, ...	1·02036	...	1·02410

Average percentage of pure sea-water at the surface 86·0, at the bottom 93·9, in vertical section 92·6, and probable mean for normal year 92·2 per cent. This station was a little salter on the surface and a little less salt at the bottom than Dog Rock, the average being practically the same.

TABLE XLIX.—*Temperature Observations off Stuckbeg.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11
Date . . .	13.4.86	17.6.86	4.8.86	5.8.86	24.9.86	12.11.86	22.12.86	8.2.87	25.3.87	7.5.87	14.6.87
No. of Points .	5	10	4	10	10	14	9	9	9	9	19
Temperature . .	41·8	43·4	45·4	45·6	47·3	48·4	47·5	45·5	43·9	44·5	46·2
Slope . . .	+1·5	+5·5	+6·9	+7·9	+7·9	+4·5	−1·5	−4·7	−0·6	+3·2	+6·0

No. . . .	12	13	14	15	16	17	18	19	20	21	...
Date . . .	7.8.87	29.9.87	15.10.87	30.11.87	9.2.88	1.3.88	28.3.88	15.8.88	3.9.88	23.10.88	...
No. of Points .	9	8	6	12	6	6	6	6	10	6	...
Temperature . .	49·8	50·3	49·9	49·1	46·0	44·1	43·3	46·3	47·0	47·0	...
Slope . . .	+11·7	+6·3	+3·4	−2·9	−1·0	+0·2	+0·3	+8·9	+10·5	+4·8	...

It is unnecessary to analyse the temperature curves in detail. As in all other places of observation, they approached a homothermic state at the annual minimum; the slope of the curves was positive during the months of heating, and negative during those of cooling. Unlike the Gareloch, however, there is no tendency to assume a homothermic state at the annual maximum, the transition from positive to negative slope being

effected, as in Loch Fyne, by a transition period of mixed slopes. When the Stuckbeg curves (figs. 19 to 21, Plate VII.) are compared with the upper 44 fathoms of the Loch Fyne curves (figs. 16 to 18), they are seen to be very similar indeed. Curves of the same date are numbered and coloured alike, and the fact appears that the conditions during the three years of observation varied similarly in both basins.

TABLE L.—*Typical Vertical Temperature Curves at Stuckbeg.*

Curve.	1886–87.			1887–88.			1888.		
	Reference Table XLIX.	Date.	Time Interval. Days.	Reference Table XLIX.	Date.	Time Interval. Days.	Reference Table XLIX.	Date.	Time Interval. Days.
I	1	April 13	...	9	Mar. 25	45	18	Mar. 28	48
II	2	June 17	65	10	May 7	43	...	...	..
III	3–4	Aug. 4–5	48	11	June 14	38	19	Aug. 15	140
IV	5	Sept. 24	51	13	Sept. 29	107	20	Sept. 3	19
V	6	Nov. 12	49	15	Nov. 30	62	21	Oct. 23	50
VI	7	Dec. 22	40	...	...	...	...	...	...
VII	8	Feb. 8	48	16	Feb. 9	71	...	...	...

It is noteworthy that in these curves the point of rapid inflection is almost always at 20 fathoms of depth, both for positive and negative slopes, and below that depth there is an approximation to homothermic change. The curves as a whole bear a considerable resemblance to those of the Arran Basin. The homothermic character of the curves points to a more thorough mixture of the water of the loch than holds good for Loch Fyne, but yet the seasonal phase was retarded at the bottom almost as much as in Loch Fyne, the bottom minimum occurring in late spring, and the bottom maximum in early spring, the rise of temperature from minimum to maximum occupying approximately nine months, and its fall to the next minimum requiring only three.

In 1886–87, which may be taken as an approach to a normal year, the range of temperature at the surface was about 14°, at 10 fathoms 9°·5, at 20 fathoms (where the abrupt change in the character of the curves begins) 6°·5, and below this depth to the bottom the seasonal amplitude remained practically the same, thus differing sharply from the condition in Loch Fyne. The retardation of the temperature phase at the bottom makes the temperature region of Loch Goil still more unlike that of the Arran Basin.

The Time-depth diagram (fig. 4, Plate III.) shows the condition of temperature-change at all depths at Stuckbeg. It very closely resembles that for Loch Fyne, so far as the depths correspond. The diagonal run of the isotherms is as well-marked here as in Loch Fyne. In 1886 it showed that the surface was above 50° from July 12th to November 6th,

the isotherm of 50° reaching its greatest. depth, 18 fathoms, on November 12th, having a much more marked diagonal trend than in Loch Fyne. The rate of descent also was far slower, 123 days being required for 18 fathoms, contrasted with 110 days for 105 fathoms at Skate Island, and 92 days for 23 fathoms in Loch Fyne. In 1887 the surface was above 50° from May 10th to October 25th, and the temperature of 50° reached its greatest depth, 20 fathoms, on November 28th, again long after the date when the isotherm had passed out at the surface during the winter cooling. On this occasion 202 days were required to carry the isotherm down to 20 fathoms (although 92 days had taken it to 19 fathoms), compared with 123 days for 30 fathoms in Loch Fyne, and 123 days for 60 fathoms at Skate Island. In 1888 the rather incomplete observations showed that the surface was above 50° from June 24th until October 23rd, and the isotherm reached its maximum depth of 11 fathoms on September 3rd, after 71 days, compared with 31 days for 12½ fathoms in Loch Fyne.

The time-depth diagram also serves to measure the retardation of the seasonal phase. In 1886 the surface maximum occurred on September 25th, while the bottom maximum was delayed until January 15th, 1887, an interval of 112 days, or 285 days after the previous bottom minimum. The retardation was at the rate of 2·5 days per fathom, compared with 2·8 days per fathom in Loch Fyne. The bottom minimum occurred on April 15th, only 60 days after the surface minimum, and 88 days after the bottom maximum. The maximum of 1887 occurred 241 days later, on December 12th, about 120 days after the surface maximum; on this occasion the retardation per fathom was 2·7 days, compared with 2·3 days for Loch Fyne. The next bottom minimum came after 109 days apparently, probably simultaneously with the surface minimum. The average retardation of the maximum for the two periods was 116 days, or practically four months, as compared with six months in Loch Fyne, and two months at Skate Island. The average ratio of the times of heating and cooling at the bottom was 263 : 84 days, or roughly, 3 to 1.

Observations at Lochgoilhead.—At this place observations were made a little to the south of the steamer pier in mid-channel, just at the commencement of the abrupt rise of the loch-bed at the head. The depth was about 25 fathoms, but observations were occasionally made opposite the pier where the depth was from 12 to 10 fathoms.

The density of water was as follows:—

	Surface.		Bottom.
Mean, 9 observations, . .	1·02236	...	1·02440
Maximum, . . .	1·02427	...	1·02465
Minimum, . . .	1·01797	...	1·02400

The average percentage of pure sea-water at the surface was 82·6, at the bottom 93·8, and in vertical section 91·9. The probable normal value in the vertical section was 91·4.

The distribution of temperature resembled on the whole that at Stuckbeg, with the differences always associated with shallower water and a position close to the upper end of a loch basin.

Temperature Sections of Loch Goil.—The deep basin of Loch Goil affords an interesting contrast to the similarly formed but much shallower basin of the Gareloch, the main difference appearing in its more sluggish temperature transactions, and, except at the yearly minimum, its generally lower temperature. The seventeen sections (figs. 1 to 17, Plates XVII. and XVIII.) are drawn on the same scale as those of the Gareloch, and are different in the ratio of horizontal to vertical scale from those of Loch Fyne.

TABLE LI.—*Temperature Observations at Lochgoilhead.*

No. . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Date . . .	17.6.86	4.8.86	24.9.86	11.11.86	12.11.86	22.12.86	25.3.87	7.5.87	14.6.87	7.8.87	29.9.87	30.11.87	10.2.88	1.3.88	28.3.88	3.9.88
No. of Pts. .	12	10	7	6	7	8	6	6	7	6	4	6	6	6	3	6
Temp. . .	44·5	47·2	48·4	50·2	49·6	47·1	44·1	45·8	50·1	52·5	54·0	48·1	45·7	44·5	43·1	42·8 5
Slope . .	+4·9	+6·7	+6·4	+0·2	+2·2	−1·5	−1·0	+2·4	+1·6	+9·4	+1·3	−1·6	−0·4	+0·3	−0·5	+4·2

Section I., 13*th April* 1886.—Observations at Dog Rock and Stuckbeg only. Flood-tide. The temperature of the mass of water below 4 fathoms sank from 42° to 41°·5. The top layer, traversed by parallel isotherms, was warmed to 44°·4 and 45°. No data were afforded for determining circulation. There was no wind.

Section II., 17*th June* 1886.—Three sets of observations were made. The isotherm of 46° ran horizontally at 4 fathoms. Below that there was a slight landward dip and fall of temperature to under 42°; above it probably a seaward dip, but want of an observation at the mouth makes this uncertain. The surface water grew steadily cooler as the loch was ascended. The tidal phase varied, and the wind was light from N.W. No sufficient indications of circulation were shown.

Section III., 5*th August* 1886.—Four stations. The isotherms were numerous, of slight and various inclination, practically horizontal. That of 44° ran at 27 fathoms instead of 12, as in June. Surface layers were warming rapidly, and the surface was growing cooler landward. The tide was at the beginning of flood, and the wind light from the south-east. The isotherms showed no disturbance on the bar. The deep water outside was practically homothermic at 49° from the bar sill to the bottom, while inside it sank to 43°·1; the bar thus shutting off cold water in the loch from water 5° warmer at the same depth outside.

Section IV., 24*th September* 1886.—Three stations; none at mouth. The isotherm of 45° ran at 25 fathoms instead of 19 fathoms, as in August. The bottom temperature inside was 44°·2, while outside it was practically uniform to the bottom at 52°, a difference of nearly 8°. Isotherms showed a very slight seaward dip, with tide at second half of ebb, and there was no wind. The fall of temperature was most rapid just below the level of the sill, there being a *Sprungschicht* at 17 fathoms. Above that the temperature was practically continuous with that outside.

Section V., 12*th November* 1886.—Three stations. Outside the sill a uniform rise of temperature occurred from surface to bottom, which was at 52°·2. Inside, the water grew warmer from 49° on the surface to 51° at sill-level, thence there was a steady fall (most rapid as in IV. in a *Sprungschicht* about 17 fathoms) to 45°·8, *i.e.*, 8°·4 lower than outside. The isotherm of 46° had moved from 19 fathoms in IV. to 36 fathoms. On the whole the isotherms showed a very slight seaward dip, a little masked by cooling at the head of the loch. The tide was in the first quarter of flood when the observations in the loch were made, and a little past high-water when the sounding was made outside. There was no wind.

Section VI., 22*nd December* 1886.—Three stations. Outside the bar a slight rise of temperature occurred with depth, from 45°·6 to 48°, with a slight minimum a little before the bottom. Inside, there was the same rise to 20 fathoms, at 25 fathoms a slight maximum of 48°·0, and then a fall to 47°·6 on the bottom. There was a slight seaward dip of the upper isotherms, but they were, as a whole, practically horizontal. The tide was in the first quarter of ebb, and the wind was fresh from the north, with rain. There was thus a surface current flowing out of the loch.

Section VII., 8*th February* 1887.—Three observations were made, viz., at Dog Rock, the Mouth, and off Carrick Castle, floating ice stopping farther work. The isotherms were horizontal, except for the increasing cold of the surface landward. Outside, 45° was found at 34 fathoms, and 45°·3 at the bottom; inside, 45° occurred at 10 fathoms, and 47°·2 at the bottom, the maximum having thus worked its way fully down, and the bar now serving to hold back warm water in the loch. The fall of temperature was very rapid at the surface, falling from 39° to 44° in $2\frac{1}{2}$ fathoms. The tide was at the first half of ebb, and the wind was imperceptible.

Section VIII., 25*th March* 1887.—Five stations were visited, the observations being very complete. The surface isotherms showed a general seaward dip. It was flood-tide, and the wind was fresh from the north, blowing against it. Outside, the temperature rose from 42°·8 on the surface to 43°·6 on the bottom; inside, below the sill it was practically constant at 44°, although an ill-defined area of slightly higher temperature appeared. Compared with No. VII., it would seem that the superficial layers remained at nearly constant temperature, while the mass below the sill had cooled down on the bottom from 47°·2 or more to 43°·9. This may be due to the mixing power of up-loch winds; but at the time of observation the down-loch wind appeared to be banking the cold surface water against the inner side of the sill of the basin and causing a partial updraught at the head.

Section IX., 7*th May* 1887.—Four stations were visited. The temperature inside below 10 fathoms was practically unchanged since No. VIII. The upper layers showed rapid heating. The isotherms were practically horizontal, and the bar might have been removed without sensibly disturbing the temperature distribution, that inside and outside being alike. It was early flood-tide, and the wind was very light from south and west.

Section X., 14*th June* 1887.—Observations were made at four stations. There was

a slight seaward dip of the upper isotherms, and a slight landward dip of the lower, with ebb-tide, and wind very light from west and south. Rapid heating of the surface layers was in progress, the surface being above 49°; a steady fall outside brought the temperature to 47° at 15 fathoms, and 45°·2 at the bottom. A fall to 45° at 15 fathoms took place inside, and from that point the temperature was practically uniform to the bottom. The fan-like spread of isotherms against the upper end of the loch strongly suggests the effects of an on-shore wind on the west coast, while the arrangement outside suggests the opposite action.

Section XI., 7th August 1887.—Four sets of observations were made. This was the section showing maximum temperature, and the isotherms were almost perfectly horizontal, with tide at the beginning of ebb and the wind varying from a light westerly breeze to calm. Outside, there was a gradually decreasing rate of fall of temperature from 58°·2 on the surface to 49° on the bottom. Inside, there was a rapid fall (equal with that outside to the edge of the bar) from 58°·6 to 47° at 23 fathoms, and then a very gradual fall to 45°·4 at bottom. Thus the bottom temperature had risen half a degree and the surface 6° since No. X.

It is interesting to note that in August 1886 the distribution of temperature was similar, and although the degree was lower, the difference of 4° between the bottom temperatures on the two sides of the barrier was the same.

Section XII., 29th September 1887.—On this occasion there were five stations, observations being exceptionally complete. A general fall of temperature had taken place in the upper layers since No. XI. The temperature was unchanged at 15 fathoms, and below that it had risen. Outside the bar the surface had cooled 4°·2, and the bottom warmed 4°·1; inside, the surface had cooled 4°·3, and the bottom warmed only 2°·1. Outside, the water was now practically homothermic at 53°·5; inside, it sank from 54°·3 to 47°·5.

The isotherms showed a strong landward dip throughout the whole depth. There was a very well marked banking-up of warm water at the head, and a distinct uprising of cold water just inside the bar. The water was evidently being driven in, in spite of the tide, which was in the first half of ebb; a strong breeze was blowing from E.N.E. As in the last and many previous cases, the isotherms about 18 fathoms lay close and parallel, indicating the plane of junction between warm upper and cool lower layers The easterly component of the wind would account for the homothermic water of the Dunoon Basin being driven into Loch Goil, and thus give rise to the thick warm layer deepening toward the head.

Section XIII., 30th November 1887.—Four stations were visited. The isotherms on the whole were horizontal. The tide was in the last half of flood, and the wind both light and variable. Continuous cooling of the upper layers had gone on, and outside the bar the whole depth had cooled down equally. Inside the bar, cooling had taken place to 20 fathoms, where the temperature was the same as in the previous month, and below that depth there was warming. At the bottom the water had reached the maximum temperature

for the year, 49°·4. Outside, the surface had cooled 11°·5, and the bottom 3°·7, since No. XII.; inside, the surface had cooled 9°·1, and the bottom had warmed 2°. The maximum temperature inside was 50° at 20 fathoms, half a degree warmer than the bottom, and 4°·8 warmer than the surface.

Section XIV., February 9th–10th, 1888.—Four stations were examined. The upper layers were distinctly warmer than in No. XIII., but the bottom was 4°·3 colder outside and 3°·2 colder inside than on the former occasion. Below the level of the bar the water outside was homothermic at 45°, that inside at 46°. The isotherms showed a strong seaward slope, indicating a mixture and out-flow of the surface water. Ebb tide preponderated, and the wind was W.N.W., or in the main down-loch, and squally. This section may be profitably compared with No. XII. for the relation of dip of isotherms to wind.

Section XV., March 1st, 1888.—Three stations only were studied. The temperature varied only from 44°·0 to 44°·9 inside, so that no evidence as to circulation was afforded. The surface (whole depth outside) had cooled down 0°·7; the bottom inside had cooled 2°. This very rapid cooling of the bottom layers, and the general equalisation of temperature throughout the basin, is characteristic of the spring minimum, but was more marked in 1888 than in 1887.

Section XVI., March 28th, 1888.—Three stations were again visited. Slight general cooling had occurred. Outside, the surface temperature was 43° (the same as in No. XV.), the bottom 42°·6, or 0°·7 colder. Inside, the surface temperature was 43°·3, the bottom 43°·1, the maximum, a little under 44°, occurring at 10 fathoms. No evidence as to circulation appeared.

Section XVII., September 3rd, 1888.—This was the last trip, and included three stations. The general distribution of temperature in its main features resembled that of the two previous Septembers, only outside the bar the surface was warmer and the bottom water colder than in former cases. The isotherms were appreciably horizontal. The fall of temperature from 56° on the surface to 51° at the level of the sill was uniform over all. Outside, the further fall to 48°·2 on the bottom was very gradual; while inside, the fall to a little under 44° was rapid and almost perfectly uniform. The minimum occurred at 35 fathoms, the bottom being a fraction of a degree warmer. As in both the previous Septembers, the bottom temperature inside was 4° lower than that outside.

From reasoning based on the great rainfall of the Loch Goil catchment basin, and the relatively high and constant salinity of the water in the loch, it is plain that there must be a double circulation always in operation, the flowing out of fresher and the flowing in of salter water. It is surprising that the isotherms show so little evidence of this circulation, especially as the contrast of temperature on the two sides of the bar is usually sharp. The only way of explaining this is that the circulation must be mainly effected by the tides, working continuously but so gradually that the small quantity of salt water brought in accommodates its temperature to that of the mass of the water in

the basin. The constancy of the *Sprungschicht* at 18 fathoms, as shown in the sections, and the striking change in the form of the curves of vertical distribution of temperature at 20 fathoms, indicate that the circulation takes place mainly in the upper half of the water; but the homothermic change of the lower half tells us that there is circulation regularly in operation to the bottom. The retardation of the maximum is proof enough that this circulation is restricted and gradual in its operation.

The average temperature of each section was ascertained by measurements on the section in the manner explained on p. 10. Tables LII. and LIII. give the weighted mean temperature of each section, and the estimated mean temperature of each slice of 10 fathoms, as well as the rate of change of temperature between successive sections. The figures so tabulated are rendered graphically in the curves of fig. 48, Plate XXXI. The air-temperature given in fig. 48 is the mean of that at Helensburgh and Callton Mor, this probably representing some approximation to the actual air-temperature over the loch itself.

TABLE LII.—*Mean Temperatures at various Depths in Loch Goil.*

Trip.	Date.	Interval. Days.	Mean Temp. of Mass Weighted.	Diff.	Mean Temperatures of Layers.			
					0–10 fms.	10–20 fms.	20–30 fms.	30–40 fms.
I.	13.4.86	...	41·84	...	42·18	41·60	41·55	41·50
II.	17.6.86	65	44·46	+2·62	46·23	43·71	42·40	42·00
III.	5.8.86	49	47·12	+2·66	49·75	45·98	44·15	43·27
IV.	24.9.86	50	48·94	+1·82	51·64	48·43	45·06	44·30
V.	12.11.86	49	49·34	+0·40	50·50	49·87	46·86	46·10
VI.	22.12.86	40	47·05	−2·29	46·35	47·38	47·86	47·90
VII.	8.2.87	48	45·11	−1·94	43·60	45·70	46·90	47·32
VIII.	25.3.87	45	43·80	−1·31	43·45	44·13	44·00	43·95
IX.	7.5.87	43	44·94	+1·14	46·03	44·20	43·97	43·92
X.	14.6.87	38	47·34	+2·40	49·62	45·99	45·05	45·00
XI.	7.8.87	54	52·34	+5·00	56·00	51·52	47·30	45·92
XII.	29.9.87	53	51·74	−0·60	53·52	51·49	49·21	48·11
XIII.	30.11.87	62	48·60	−3·14	47·35	49·39	49·85	49·60
XIV.	9.2.88	71	45·70	−2·90	45·35	45·90	46·05	46·15
XV.	1.3.88	21	44·10	−1·60	44·19	44·05	44·00	44·03
XVI.	28.3.88	27	43·42	−0·68	43·33	43·50	43·50	43·48
XVII.	3.9.88	...	50·05	...	53·34	49·10	45·95	44·10

These curves of temperature at different depths present much similarity to those of Loch Fyne (fig. 41, Plate XXX.). The air-curve is practically the same, though the maxima for 1886 and 1888 are rather higher than for Loch Fyne. The curve of mean temperature of

the surface layer of 5 fathoms is of considerably greater amplitude, and a little earlier in phase than that for Loch Fyne, corresponding more closely with that for the Gareloch (fig. 47, Plate XXXI.). In 1886 the curve is so flat, and the apparent maximum so late and low, that it seems possible that the true maximum fell between the dates of observation. On the other hand, the rate of heating was less throughout than in other years, and it may be that the exceptionally low minimum temperature of the spring gave rise to the retardation. It is difficult, however, to account for the rate of surface heating being less in Loch Fyne, whereas in subsequent years it was greater. Probably the fact was due to local causes, such as the direction and force of the wind, or to the amount and temperature of the rainfall entering the loch, and it is, unfortunately, impossible to obtain data for these conditions.

The bottom layer of Loch Goil gave a curve corresponding closely in form and irregularities with that of the layer between 30 and 40 fathoms in Loch Fyne; but in 1886 its range was less, on account of a lower maximum, and the period of the maximum was both in 1886 and 1887 fully a month later than that of water at the same depth in Loch Fyne, occurring as it did about the end of December. The retardation was not so great as for the bottom water of Loch Fyne, but approached it sufficiently to show that the steepness of the sides of a basin has a great deal to do with the temperature *régime* of its water, and that depth alone does not condition the manner and rate of change. The maximum of the bottom layer was retarded about 180 days after the air maximum in 1886, and 150 days in 1887, comparing with 126 and 120 days for the retardation of the maximum at the same depth (30–40 fathoms) in Loch Fyne. In the two years the rate of sinking of the maximum was very nearly the same; for the maximum temperature at 20 fathoms it was 60, at 25 fathoms 90, and at 40 fathoms 105 days later than at 5 fathoms, while in Loch Fyne the retardation was 20, 30, and 60 days respectively; the average retardation at the bottom being only 105, although the depth is twice as great as in Loch Goil. Thus the isolation of the Loch Goil basin is twice as efficient as that of Loch Fyne.

Considering the variations in temperature of the mass of water in Loch Goil, it is found that from the minimum of 42° to the maximum of 49°·6 in 1886, the time was 198 days, and the rate of heating only 0°·038 per day. This was a longer period of heating by 30 days than in Loch Fyne, and by 45 days than in the Gareloch, while the rate of heating was less than half that of the Gareloch, and less by one-quarter than that of Loch Fyne. The following cooling period was 144 days, when a minimum temperature of 43°·8 was reached, the daily rate of cooling being 0°·040. This was practically the same rate of cooling as for Loch Fyne, but the time was 12 days less, and 22 days less than the Gareloch. In 1887 the maximum was 53°·0 after 160 days' heating at the rate of 0°·058 per day, nearly as much longer and slower than the Gareloch as it was shorter and quicker than Loch Fyne. The succeeding minimum of 43°·4 was reached by an average cooling of 0°·046 in 210 days, the rate being the same as in Loch Fyne, but the time 26 days longer, although 41 days shorter than in the Gareloch.

The period of warming in 1888, up to probably 51°·2, was about 180 days, at the rate of 0°·043 per day. The average time of heating for the three years was 179 days in Loch Goil, and the average time of cooling for the two seasons 177. In 1888 it happened curiously enough that the period of heating was the mean of the two earlier years, so that for the two years comparable for the whole Area the ratio of time of heating to time of cooling was 179 : 177 or 100 : 99. Taking 100 as representing the duration of heating, the duration of cooling in the different divisions was :—

Gareloch.	Channel.	Arran Basin.	Loch Goil.	Loch Fyne.
130	115	100	99	91

Judged in this way, the two divisions, where the surface-temperature is always close to the average temperature of the water, would seem to heat up more quickly than they

TABLE LIII.—*Average Change of Temperature* per diem *in Loch Goil.*

Date.	No. of Days.	Mass of Water.	0–10 Fathoms.	10–20 Fathoms.	20–30 Fathoms.	30–40 Fathoms.
17.6.86	65	+0·040	+0·062	+0·032	+0·013	+0·008
3.8.86	49	+0·054	+0·072	+0·046	+0·036	+0·026
24.9.86	50	+0·036	+0·038	+0·049	+0·018	+0·021
12.11.86	49	+0·008	−0·023	+0·029	+0·037	+0·037
22.12.86	40	−0·057	−0·104	−0·062	+0·025	+0·045
8.2.87	48	−0·040	−0·057	−0·035	−0·020	−0·012
25.3.87	45	−0·029	0·000	−0·036	−0·056	−0·077
7.5.87	43	+0·027	+0·060	+0·000	−0·000	−0·000
14.6.87	38	+0·063	+0·095	+0·047	+0·028	+0·028
7.8.87	54	+0·093	+0·118	+0·102	+0·042	+0·017
29.9.87	53	−0·011	−0·047	0·000	+0·036	+0·041
30.11.87	62	−0·051	−0·100	−0·034	+0·010	+0·024
9.2.88	74	−0·040	−0·028	−0·048	−0·053	−0·048
1.3.88	21	−0·076	−0·055	−0·088	−0·098	−0·101
28.3.88	27	−0·025	−0·003	−0·002	−0·002	−0·002
Mean Heating . . .		+0·046	+0·074	+0·051	+0·028	+0·027
No. of Cases . . .		7	6	6	9	9
Mean Cooling . . .		−0·041	−0·052	−0·043	−0·046	−0·048
No. of Cases . . .		8	8	7	5	5
Mean Change . . .		0·043	0·061	0·047	0·034	0·034

cool, while those in which depth and isolation retard temperature changes gain and lose heat, on the whole, at the same rate; or, as in the case of Loch Fyne, cooling is more rapid than heating. The fact that the two years, 1886 and 1887, were very unlike in their thermal relations deprives these averages of any general application in the case of Loch Goil.

The rate of change of temperature in fractions of a degree per day is shown in Table LIII., and, together with the same data for Loch Fyne, graphically in fig. 42, Plate XXX. The mean daily change of temperature for the whole mass is 0°·043, or a change of one degree in 23 days, as compared with one degree in 13½ days for the Gareloch, and in 25 days for Loch Fyne. For the surface layer of 10 fathoms it is 0°·061, or one degree in 16½ days, compared with 19 for Loch Fyne. From 10 to 20 fathoms the rate of change was the same in Loch Goil and Loch Fyne; from 20 to 30 fathoms the Loch Fyne change was slightly greater, and from 30 to 40 fathoms both were alike, 30 days being required for a change of one degree.

As in all other cases, the descending curve of air-temperature cut the curve of surface-temperature at the maximum, and also cut the curve of mass-temperature at its maximum a month or so later. In each case the ascending air-curve cut the others about 10 or 15 days after their minimum.

The air was warmer than the surface layer of 5 fathoms for 172 days in 1886, 104 in 1887, and 132 in 1888, averaging 136 days for the three periods; while it was colder than the surface layer for 224 days in 1886–87, and 248 in 1887–88, an average of 236 days. The average of the two seasons is 138 days of air warmer, and 236 days of air colder than surface water, or 4½ months to 7½. This was exactly intermediate between the data for the Gareloch and Loch Fyne, in the former the period of warmer air being shorter, and in the latter longer than in any other division.

TABLE LIV.—*Mean Annual Temperature of Air and Water for Loch Goil.*

Year.	I. Air. Mean for Area.	II. Air. Mean for Helensburgh and Callton Mor.	III. Water. 0–5 Fathoms.	IV. Water. Mass.	Difference Air II. and Water III.	Difference Air II. and Water IV.
1886	46·2	46·0	47·1	45·7	−1·1	+0·3
1887	47·0	46·4	48·9	47·9	−2·5	−1·5
1888	46·7	46·9	47·9	47·1	−1·0	−0·2
Mean	46·63	46·43	47·97	46·90	−1·54	−0·47

By interpolating probable values for the first three months of 1886 and the last three months of 1888 the curve (fig. 47, Plate XXXI.) gives the means of estimating the average annual temperature of the three years. This is given in Table LIV.

The average temperature of the surface layer for the whole time of observation was

the same in Loch Goil and the Gareloch, and rather less than half a degree higher than the surface layer in Loch Fyne. The temperature of the mass of the water in Loch Goil was on the average half a degree higher than in Loch Fyne. The mean annual temperature of the surface layer in Loch Goil was 1°·5 higher than the air-temperature for the years 1886–87, the same as for Loch Fyne, and about quarter of a degree less than for the other divisions. The mass of water in Loch Goil, like that in Loch Fyne, averages 0°·4 higher than the air.

All the observations show that, proportionally to its depth, temperature changes are more restricted in Loch Goil than in Loch Fyne, with which alone it can be compared, and its isolation from oceanic influences appears to be more complete.

Loch Strivan.

Loch Strivan is an example of a loch basin imperfectly shut off from the Arran and Dunoon Basins by the broad and not very shallow Bute Plateau, and connected with the Arran Basin also, so far as superficial water is concerned, by the narrow and tortuous channel of the Kyles of Bute.

The loch is described in its physical features in Part I. p. 648. It differs from the other loch basins mainly in having no sharply-defined bar, and in its breadth diminishing uniformly from its mouth to the head. The section along the axis of the loch given in Part I., Plate 8, No. 12, brings out its peculiar form, the deepest channel across the Bute Plateau being 25 fathoms, while the greatest depression of Loch Strivan is only 42. For the steepness of its hill-slopes this loch may be compared to Loch Goil or the upper basin of Loch Fyne, while with respect to its easy communication with the sea the most similar subdivision of the Area is the Central Arran Basin.

Observations were usually made between Toward and Bogany on the Bute Plateau, frequently in Rothesay Bay, at the topographical mouth of Loch Strivan in mid-channel off Strone Point, at Clapochlar in the deepest water rather more than half way up the loch, and in shallow water close to the head of the loch. The weather was more frequently stormy or wet whilst this division was being examined than in the case of any of the others, its free opening to the south allowing the swell coming up the Channel between Bute and the mainland to run straight up the loch.

The curves of vertical distribution of temperature need not be considered here in detail. They conformed, as a rule, to the types of the Arran Basin, rarely showing an approach to those of Loch Goil. On several occasions these curves showed high hetero-thermicity, layers of water at different temperatures being sharply superimposed almost without mixture.

I propose here to deal with the change of temperature of the loch as a whole as deduced from the temperature sections constructed for each trip. An exception may, however, be made with regard to the time-depth diagram at Clapochlar (fig. 5, Plate VI.). It corresponds in depth with Stuckbeg, and shows a restricted circulation in the lower

layers comparable with that of Loch Goil, though much less marked. In 1886, the diagram shows that the surface water was above 50° from July 10th to October 18th, or three weeks shorter than at Stuckbeg, but the temperature of 50° reached the bottom by October 15th, and the water there remained warmer than 50° until December 5th, whereas in Loch Goil the maximum depth to which this isotherm reached was 18 fathoms on November 12th. In 1887, the surface was over 50° from June 12th until November 12th, and the bottom was at or above this temperature from November 20th until December 5th, whereas in Loch Goil the greatest depth reached by the isotherm was 20 fathoms on November 28th. The persistent low temperature of the lower layers in the summer of 1887 was remarkable. In 1888, the surface was above 50° from July 7th until after the end of October, but on this occasion the greatest depth reached by the isotherm was 25 fathoms on September 24th, contrasted with a depth of 11 fathoms on September 3rd in Loch Goil. The isotherms became vertical at the minima, showing the phenomenon of homothermic change for a considerable time before and after that period.

Temperature Sections of Loch Strivan.—These sections (figs. I. to XXIII., Plates XIX. and XX.) are twenty-three in number.

I. 14*th April* 1886.—A general seaward dip was noticeable in the upper isotherms, corresponding to a northerly breeze blowing almost directly down the loch; but below the depth of 5 fathoms the water was practically homothermic.

II. 17*th*–18*th June* 1886.—The water was well stratified in temperature, all the isotherms showing a pronounced seaward dip. The isotherm of 45° was 1 fathom deep at the head, and 15 fathoms at Bogany, while that of 43° dipped from 4 fathoms at the head to 40 fathoms half-way down the loch. The wind on both days varied from north-west, light, to N.N.W., fresh, blowing straight down the loch, and obviously driving the warm surface water seaward while the deeper layers welled up at the head. This fact was proved absolutely by density observations, showing that the surface water at the head of the loch was as salt as the bottom water in the deepest place, while the surface water at Bogany was very much fresher. On this occasion the surface water at the head of Loch Strivan was salter than that at any other observed position in the Clyde Sea Area. The tide in Loch Strivan on this occasion was about half-flood, so that it tended to reduce the effect of wind circulation.

III. 7*th August* 1886.—The temperature throughout had increased rapidly since June, but the slope of the isotherms was still seaward in the main. In the upper part of the loch the isotherms were close and horizontal, indicating rapid surface-heating, probably due to the warmth of the air. The wind varied from N.N.W. to west, and was light; on the previous day it had been southerly.

IV. 25*th September* 1886.—A very marked rise of temperature had taken place mainly, it would appear, by the entrance of warm and nearly homothermic water from the Dunoon or Arran Basin. The ill-defined barrier at Bogany now served to separate water with temperatures from 50° to 48° from the warmer water at 51° to 53° outside.

The isotherms were practically horizontal, and the wind was light from the south and south-west.

V. 13*th November* 1886.—Autumnal conditions had by this time fully set in, and the barrier had no effect of separating water at different temperature. Below 5 fathoms the water was homothermic about 51°·5, above that it grew cooler to the surface, the isotherms showing no perceptible dip. The wind was northerly and very light.

VI. 23*rd December* 1886.—Rapid cooling had taken place throughout the whole mass of water, and the few isotherms which appeared on the section showed a slight seaward dip in the deeper layers, but were practically horizontal near the surface, thus showing no sign of any disturbance of equilibrium. The wind was variable, but very light.

VII. 7*th February* 1887.—Although the range of temperature in this section was small, the run of the isotherms was somewhat peculiar, probably representing the result of some considerable previous disturbance. A wedge of warm water (over 45°) ran at the depth of 15 fathoms from the head of the loch to beyond Clapochlar, with cooler water above and below. The upper 10 fathoms at Clapochlar were homothermic at 42°, but at the head and in the Dunoon Basin, on the other side, the surface-temperature was below 40°. The wind was blowing pretty strongly from south-east and south, or straight up the loch, but the dip of the isotherms was too slight and indefinite to show the direction of circulation.

VIII. 20*th March* 1887.—In this section the conditions were almost homothermic: the one isotherm, of 44°, which appeared showed a marked seaward dip at the head of the loch, but the total range between surface and bottom being only 0°·4, no argument can be based upon it. The wind was very light from the west and south-west.

IX. 6*th May* 1887.—Surface warming had fairly set in, and the isotherms showed a slight seaward dip as far as Bogany. The wind was light from the north-west and north, thus affording a sufficient explanation for the temperature diminishing from the mouth to the head of the loch.

X. 14*th June* 1887.—A typical section of summer heating is here presented. The isotherms, although varying in their inclination, showed on the whole a slight seaward dip. There was no wind at the time of observation. The patch of water below 46° over the plateau at the mouth of the loch appears as a striking feature in the section, but is in reality inconsiderable, as the temperature falls only a fraction of a degree lower.

XI. 13*th*–14*th August* 1887.—This section resembles those for the previous August and September by illustrating the function of the plateau in barring off the cooler water inside from the warmer mass entering from the Arran and Dunoon Basins. There was a strong seaward dip of the isotherms from the head to Clapochlar, a horizontal run thence to Bogany, beyond which the lines spread out. This was well defined by the *Sprungschicht* between the temperatures 51° and 54°, and by the cooling of the surface water (contrary to the usual order in summer) from 56°·2 at Clapochlar to 54°·8 at the Head. A fresh breeze blowing from the north-east accounted for this state of matters.

XII. 28*th September* 1887.—In this section autumnal conditions are well shown. The warmest water, homothermic at 54°·5, was in the Arran and Dunoon Basins, but gradually gave place to heterothermic conditions on the Bute Plateau, where lower temperatures reigned on the bottom, and inside the loch basin lower still. In the loch the surface water had cooled down a little, so that there was an intermediate layer at a slightly higher temperature, but a slight tilt of the isotherms caused the upper cold layer to thin away toward the head of the loch where the warm zone came to the surface. A slight north-easterly breeze was blowing down-loch at the time. Below the level of the bar the isotherms were apparently horizontal.

XIII. 2*nd December* 1887.—Four of the most interesting sections made during the whole course of the work on the Clyde Sea Area record the results obtained by Dr MURRAY in December 1887, and three of these he has described * in an article discussing the effect of wind on the circulation of water. They are included here in order to complete the set. On December 2nd the ordinary winter condition was established, a mass of warm water occupying Loch Strivan covered over and shut in seaward by colder water. The isotherms dipped strongly seaward, showing an up-draught of the warmer water at the head of the loch, and an in-draught of the colder bottom water from outside across the Bute Plateau. The wind was blowing a stiff breeze from W. by N., mainly transverse to the loch, but with a down-loch component which would become more powerfully felt at the junction with the Dunoon Basin, off Bogany.

XIV. 14*th December* 1887.—The change brought about in the twelve days elapsing since the last section was drawn was very remarkable. At the earlier date the surface-temperature was everywhere 48° or more, on the 14th it was 45° at the mouth of the loch, and diminished to 39°·3 at the head, where the water was muddy and quite fresh. The most interesting feature was a *Sprungschicht* in which the temperature rose from 44° to 48° in a fathom and a half, at a mean depth of 6 fathoms. Beneath, the temperature was almost homothermic at 49°; above, almost homothermic at 43°. A gale from the south-west was blowing up the loch, banking up the cold fresh-water at the head, and causing the *Sprungschicht*, raising the warmer deep water to the surface at the mouth, where the isotherms of the *Sprungschicht* spread out like a fan. The disturbance due to wind at no point reached deeper than 10 fathoms.

XV. 15*th December* 1887.—This section represents the distribution of temperature twenty hours later than No. XIV.; in the meantime, the wind had fallen calm, and changed to a northerly direction. The air was cold, and ice formed on the nearly fresh water at the head of the loch. The up-loch dip of the isotherms had almost disappeared, except in the upper layer. The *Sprungschicht* had risen to 5 fathoms at the head, and as its component isotherms spread out down the loch, they assumed a marked seaward dip, indicating a reversal of the direction of vertical circulation. The homothermic layer in the deep part of the loch remained as before, but on the Bute Plateau the conditions had become heterothermic throughout.

* *Scottish Geographical Magazine*, iv. (1888), p. 351.

XVI. 19*th December* 1887.—A strong northerly wind was blowing down the loch, and all the isotherms showed, accordingly, a strong seaward dip. The water at the head of the loch was salt and clear, and was the warmest surface-water in the section, 48° compared with 43°·7 at the mouth. The run of the isotherms suggests that the deep water was being drawn up all along the section, and the reverse dip of the lower isotherms of 48° at the mouth, indicates the drawing in of colder water along the bottom.

The three sections illustrate admirably the rapidity with which the entire vertical circulation of a long narrow basin may be reversed.

XVII. 8*th January* 1888.—The water had by this time assumed a nearly homothermic condition, and had greatly cooled. The one prominent isotherm in this section, however, dipped strongly seaward. The wind was variable and squally, shifting from north-west and north-east to south.

XVIII. 27*th January* 1888.—The wind was blowing a heavy gale from N.N.W. and north when the observations for this section were taken, and the solitary isotherm (45°·5) it bears, dipped seaward, as might be expected. The extreme range of temperature was from 45°·0 to 45°·8, and this approximation to homothermicity was undoubtedly largely due to the mixing effect of the strong wind.

XIX. 11*th February* 1888.—This is another almost homothermic section, showing, by a curious coincidence, a wedge-shaped inclusion of warmer water nearly in the same position as in February 1887 (see Section VIII.), and, like it, bounded by the isotherm of 45°. For the rest the water was simply homothermic, its extreme range, but for this inclusion, being from 44°·4 to 44°·8. The wind was northerly and light.

XX. 29*th March* 1888.—Here a minimal section presents an unusually complicated character, the central mass of the water being a little warmer than 43°, while above and seaward the water cools to 42°·1, and below it cools to 42°·8. The total range is so small that one cannot found any argument upon the run of the isotherms. There was a light north-east wind.

XXI. 9*th June* 1888.—This is a mere fragment, showing the surface layers stratified by perfectly horizontal isotherms. The wind on this occasion was a light breeze from the west, and Dr MURRAY found that the surface water along the side of off-shore wind was about 48°, and on the side of on-shore wind about 51°. In the fraction of axial section the surface was at 49°·5. This shows how a transverse disturbance of the water may give no trace in a longitudinal section, even while very considerable mixing may be in progress.

XXII. 20*th September* 1888.—A typical "heating" section with isotherms on the whole horizontal is here given. Above 15 fathoms the isotherms were concave upward, and below that plane they dipped seaward, indicating possibly an inward current of nearly homothermic water over the Bute Plateau, and a slight upwelling at the head, which does not, however, extend quite to the surface. The wind was light from the north-east.

XXIII. 20*th October* 1888.—This section shows a very close approach to homothermicity in the initial stage of cooling, the extreme range being from 50°·5 on the sur-

face to 49°·8 at the bottom. The state of matters is similar to that common at the same season in the Gareloch, but not shown in the deeper lochs. A light breeze was blowing, varying from east to south-east; but, of course, the section affords no evidence of circulation.

Taken as a whole these sections show that Loch Strivan is, from its physical and geographical peculiarities, the most subject of all the Clyde lochs to have its waters mixed and set in motion by the wind.

Seasonal Variation of Temperature.—Fig. 49, Plate XXXII., shows the seasonal variation of the temperature of the air at Rothesay, and of the water of Loch Strivan, considered for the superficial layer of 5 fathoms, the deepest layer between 30 and 40 fathoms, and the mass of the water taken as a whole, the temperatures being calculated from the sections.

The relations between these curves differ entirely from those of Loch Goil or Loch Fyne, showing a resemblance rather to the curves of the more open Basins. The retardation of the date of maximum temperature, after that of the air, was for the superficial 5 fathoms 45 days, and for the bottom 10 fathoms 105 days, in 1886; the corresponding figures for 1887 were 39 and 119; an average for the two years of 42 days for the surface, and 112 days for the bottom layer. The average retardation of the maximum was 165 days in Loch Goil, and 123 days in Loch Fyne, at the depth of 30 to 40 fathoms, indicating the more rapid circulation of Loch Strivan.

The periods of heating and cooling of the mass of water in Loch Strivan—calculated from the curve—may be compared with those of the other divisions given in Table XLV. The time is in days; the rate, degrees per day.

TABLE LV.—*Period of Heating and Cooling, and Daily Rate of Change of Temperature, in Loch Strivan.*

Heating, 1886.	Rate per day.	Cooling, 1886–87.	Rate per day.	Heating, 1887.	Rate per day.	Cooling, 1887–88.	Rate per day.	Heating, 1888.	Rate per day.
180	0·060	155	0·059	202	0·049	198	0·052	186	0·050

The minimum and maximum temperatures of the mass of water, so far as they can be deduced from the curves, are:—41°·8, April 15th, 1886; 52°·4, September 26th, 1886; 43°·3, March 1st, 1887; 53°·2, September 18th, 1887; 42°·9, April 4th, 1888; and 52°·2, September 27th, 1888. In duration and rate these figures correspond best with those of the Arran Basin. Considering the two periods which can be compared in all the divisions, we find the average number of days of heating and cooling respectively to be—191 and 177, or in the ratio of 100 to 93. In this respect—the greater duration of heating than cooling—the affinity is with Loch Fyne, where the ratio was 100 : 91, rather than with the Arran Basin, where it was 100 : 100.

Table LVI. gives concisely the mean temperatures of the various layers of depth into which the sections were divided for convenience of calculation, and Table LVII. represents similarly the rate of change of temperature between consecutive observations. The curves giving graphical expression to this table are not reproduced, as in the main they merely repeat the general features of other curves of rate of change. In both the tables only one of the temperature trips of December 1887 is included, in order to ensure some approximation to the same order of magnitude in the intervals considered.

TABLE LVI.—*Mean Temperatures at Various Depths in Loch Strivan.*

Section.	Date.	Days from Last.	Mean Temperatures.				
			Mass Weighted Mean.	0–10 fms.	10–20 fms.	20–30 fms.	30–40 fms.
I.	14.4.86	...	41·80	42·23	41·47	41·40	41·30
II.	17.6.86	64	44·90	46·51	43·81	43·14	43·07
III.	7.8.86	51	49·24	50·83	48·57	47·34	45·98
IV.	25.9.86	49	52·04	53·45	51·74	50·07	48·50
V.	13.11.86	49	50·46	49·40	51·20	51·59	51·55
VI.	23.12.86	40	46·57	45·87	46·93	47·38	47·97
VII.	7.2.87	46	43·45	42·37	44·73	44·00	44·00
VIII.	20.3.87	41	43·65	43·45	43·70	43·89	44·00
IX.	6.5.87	47	44·80	45·33	44·44	44·26	44·15
X.	14.6.87	39	48·19	49·60	47·59	46·27	46·05
XI.	13.8.87	60	52·18	55·01	52·00	49·66	48·26
XII.	28.9.87	46	53·04	53·83	53·32	51·69	49·65
XIII.	2.12.87	65	49·25	48·89	49·38	49·69	50·10
XVII.	8.1.88	37	45·88	45·64	45·99	46·19	46·40
XVIII.	27.1.88	19	45·23	45·18	45·39	45·56	45·70
XIX.	11.2.88	15	44·67	44·58	44·74	44·76	44·75
XX.	27.3.88	45	42·84	42·71	43·04	42·87	42·85
XXI.	20.9.88	177	52·07	53·80	51·39	49·95	48·55
XXIII.	20.10.88	30	50·34	50·35	51·13	50·02	49·90

Table LVII. may be compared with Table LIII., which gives the corresponding data for Loch Goil. In both lochs the rate of change of temperature in the surface layers is the same, 0°·062 per day, or equivalent to 1° in 16½ days; but the average change of the whole mass is 0°·053 per day, or 1° in 19 days, contrasted with 23 days for Loch Goil and 13½ for the Gareloch. From 30 to 40 fathoms the rate of change in Loch Strivan was more rapid than in the other deep lochs, being equivalent to 1° in 20½ days as compared with 30 in the other cases. The peculiarity visible in Loch Goil

of a gradual diminution in the rate of heating as the depth increased until, in the bottom layer of 10 fathoms, the rate was scarcely more than half that in the surface layer, was also shown in Loch Strivan; and a corresponding increase in the rate of cooling as the depth increased (leaving out of account, in this case, the superficial 10 fathoms). In

TABLE LVII.—*Average Change of Temperature* per diem *in Loch Strivan.*

Trip.	No. of Days. Interval.	Mass.	0–10 fms.	10–20 fms.	20–30 fms.	30–40 fms.
17.6.86	64	+0·048	+0·051	+0·037	+0·027	+0·028
7.8.86	51	+0·085	+0·085	+0·093	+0·082	+0·057
25.9.86	49	+0·057	+0·053	+0·065	+0·056	+0·051
13.11.86	49	−0·032	−0·083	−0·001	+0·031	+0·062
23.12.86	40	−0·097	−0·088	−0·107	−0·105	−0·089
7.2.87	46	−0·068	−0·076	−0·048	−0·073	−0·086
20.3.87	41	+0·005	+0·026	−0·024	−0·002	−0·000
6.5.87	47	+0·034	+0·040	+0·016	+0·008	+0·003
14.6.87	39	+0·087	+0·109	+0·077	+0·049	+0·046
13.8.87	60	+0·066	+0·090	+0·074	+0·057	+0·037
28.9.87	46	+0·019	−0·026	+0·029	+0·044	+0·030
2.12.87	65	−0·058	−0·076	−0·060	−0·030	+0·007
8.1.88	37	−0·091	−0·088	−0·092	−0·095	−0·100
27.1.88	19	−0·034	−0·024	−0·032	−0·033	−0·037
11.2.88	15	−0·037	−0·040	−0·043	−0·053	−0·064
27.3.88	45	−0·040	−0·042	−0·038	−0·042	−0·042
Mean Heating . .		+0·050	+0·065	+0·056	+0·044	+0·035
No. of Cases . .		8	7	7	8	9
Mean Cooling . .		−0·057	−0·060	−0·049	−0·054	−0·069
No. of Cases . .		8	9	9	8	6
Mean Change . .		0·053	0·062	0·052	0·049	0·049

the surface layer the rates of heating and cooling were nearly equal, that of heating being 8 per cent. greater, but the rate of heating diminished, and that of cooling increased so rapidly that, at the bottom, cooling was twice as rapid as heating; the disparity being somewhat greater than in Loch Goil. The bottom curve, in fact (see fig. 49, Plate XXXII.), rose only half as rapidly as the surface curve, but fell at the same rate to a simultaneous minimum. The air curve cut both the surface and the mass temperature

curves practically at the maxima. The air was warmer than the superficial 5 fathoms of water for 164 days in 1886, 126 in 1887, and 134 in 1888, an average of 141; and the air was colder than the superficial layer for 220 days in 1886–87, and 230 in 1887–88, an average for the two seasons of 225 days. The average of the two complete cycles is 145 days of air warmer than water, and 225 of water warmer than air, or rather more than 4½ months of the former to rather less than 7½ months of the latter. The proportions being very similar to those for the other divisions.

By interpolating probable values for the earlier months of 1886 and the later of 1888, we are able to present in Table LVIII. the approximate annual mean temperatures of water and air in Loch Strivan.

TABLE LVIII.—*Mean Annual Temperature of Air and Water for Loch Strivan.*

Year.	I. Air. Mean for Area.	II. Air. Mean for Rothesay.	III. Water. 0–5 fathoms.	IV. Water. Mass.	Difference. Air II. and Water III.	Difference. Air II. and Water IV.
1886 . .	46·2	46·4	47·0	46·4	−0·6	0·0
1887 . .	47·0	47·4	48·6	48·1	−1·2	−0·7
1888 . .	46·7	46·9	48·2	47·3	−1·3	−0·4
Mean .	46·63	46·90	47·91	47·27	−1·01	−0·37

As regards the excess of the temperature of the mass of the water in Loch Strivan over that of the air, the result is the same as for Loch Fyne and Loch Goil; but the excess of surface-temperature is less than in any other division. For the average of the two years, 1886 and 1887, the surface water was warmer than the local air-temperature to the following amount:—In the Channel, 1°·7; Arran Basin, 1°·7; Loch Fyne, 1°·5; Gareloch, 1°·8; Loch Goil, 1°·8; and Loch Strivan only 0°·9. This fact is evidently connected with the ease with which the water of Loch Strivan is mixed by wind throughout its whole depth; thereby the mass of its water is brought more fully in contact with the air than in any other division.

The average temperature of the surface water for the three years under observation was the same for the Gareloch, Loch Goil, and Loch Strivan, this being about half a degree higher than for Loch Fyne.

THE DUNOON BASIN.

The Dunoon Basin is here considered as the channel extending from the end of the north-eastern branch of the Arran Basin, past Dunoon and up "Lower Loch Long,"

terminating at the bar which separates Loch Goil, and at the entrance to Upper Loch Long, just beyond the depression at Dog Rock.

The set of observations in this division was usually an interrupted one, and rarely, if ever, were all the stations studied on the same day. Consequently, the sections which were drawn are somewhat less trustworthy than those for the lochs, and it has not been considered necessary to reproduce them. They were, however, quite serviceable for calculating the average temperature of the water on the occasion of each trip, and this was done in order to compare the temperature changes as a whole with those of the other divisions. Table LIX. gives the calculated temperature of the layers and of the mass of water as a whole; and Table LX. shows the rate of change of temperature between the dates of successive sections. The curves at the various stations did not differ much from those for water of the same depth in the Arran Basin, except in the case of the Dog Rock observations, which showed some affinity to those in the deep lochs. (See Loch Goil, p. 122.)

The time-depth diagrams for the station off the Gantock Beacon opposite Dunoon, and for the Dog Rock sounding, reproduced in figs. 10 and 11, Plate VI., show a general homothermic change in the deeper layers with a slightly greater restriction at Dog Rock. At the latter station contorted curves, showing layers of water varying irregularly in temperature, were very frequently found, due probably to the outflow from Loch Goil and Loch Long entering at different levels the mass of water in the Dunoon Basin.

These diagrams show that in 1886 the temperature on the surface was above 50° from June 28th to October 28th at Gantock, and from May 10th to October 25th at Dog Rock, as compared with July 10th to November 6th in Loch Goil, where the greatest depth reached by that temperature was 18 fathoms. In contrast, the bottom water at Gantock was over 50° from August 27th to October 30th, and at Dog Rock from August 30th to December 8th. The observations for 1887 and 1888 showed exactly the same arrangement, with some slight differences of date.

At Gantock the retardation of the date of maximum bottom temperature after the surface averaged 27 days, at Dog Rock 40 days, and in Loch Goil, at Stuckbeg, 116 days. The retardation of the minimum temperature at the bottom was 16 days after that at the surface at Gantock, 37 at Dog Rock, and 38 at Stuckbeg. The contrast is greatest between Dog Rock and Stuckbeg, the retardation of both maximum and minimum being practically equal at the former, while at the latter the descent of low temperature took place at the same rate, but the descent of the high temperature wave took three times as long. The date of surface maximum and of surface minimum corresponded closely for all three stations. The average number of days during which heating and cooling continued for the two complete periods was in the order—Stuckbeg, Dog Rock, Gantock—186 : 165, 169 : 168, 182 : 157 for the surface, and 255 : 105, 172 : 180, 189 : 171 for the bottom. Thus, at Stuckbeg, the water was 21 days longer in heating than in cooling at the surface, and 150 days longer in heating than in cooling at the bottom. At Dog Rock the time was the same, both for heating and

cooling at the surface, but at the bottom the period of heating was 8 days shorter than that of cooling. At Gantock, on the other hand, the surface water required 25 days, and the bottom water 18 days longer to heat than to cool.

The contrast in this particular is the remarkable lengthening of the period of heating and diminution of the period of cooling at the bottom in the enclosed loch ; or, since the time required for a given change of temperature is the reciprocal of the rate of change, the average rate of heating is smaller and that of cooling much greater in an enclosed than in a relatively open basin. This is evidently due to restriction of circulation in the water.

TABLE LIX.—*Mean Temperature at Various Depths in Dunoon Basin.*

Section.	Date.	Interval. Days.	Mean Temperatures.						
			Mass (Wtd.).	5 fms.	15 fms.	25 fms.	35 fms.	45 fms.	55 fms.
I.	17.4.86	...	42·12	42·70	41·85	41·70	41·50	41·45	41·40
II.	19.6.86	62	45·78	47·75	44·82	44·17	44·00	43·94	44·23
III.	6.8.86	48	49·33	50·86	48·64	48·05	47·89	47·83	47·40
IV.	26.9.86	51	52·74	52·97	52·80	52·46	52·27	51·89	51·85
V.	12.11.86	47	50·95	50·43	51·20	51·36	51·47	51·54	51·36
VI.	24.12.86	42	46·34	45·62	46·52	46·99	47·38	47·46	47·24
VII.	6.2.87	44	43·75	43·00	44·13	44·32	44·48	44·50	44·50
VIII.	24.3.87	52	43·28	43·18	43·26	43·41	43·50	43·53	43·60
IX.	7.5.87	45	44·86	45·73	44·42	44·19	44·10	44·16	44·27
X.	14.6.87	38	48·88	51·00	48·34	46·79	46·28	46·13	46·30
XI.	7.8.87	44	54·01	55·80	53·86	52·09	51·15	50·82	50·83
XII.	30.9.87	54	54·01	54·19	54·03	54·01	53·94	53·85	53·79
XIII.	30.11.87	61	48·26	48·00	48·50	48·40	48·35	48·35	48·30
XIV.	11.2.88	73	44·34	44·28	44·28	44·47	44·51	44·55	44·39
XV.	8.3.88	25	44·01	44·30	43·71	43·88	44·05	44·12	44·25
XVI.	28.3.88	20	42·29	42·05	42·43	42·48	42·46	42·36	42·38

Fig. 50, Plate XXXII., gives the seasonal change of temperature of the air over the Dunoon Basin taking this as the mean of the air at Greenock and Rothesay, of the superficial 5-fathom layer of water, and of the layer between 30 and 40 fathoms, as well as of the mass of water. The period represented comprises two maxima and three minima. In their general form the curves resemble those of the Arran Basin and Loch Strivan, showing the characteristic lag of the deeper layers in heating, and the much less obvious lag of the deeper layers in cooling.

The retardation of the period of maximum in the surface water (5-fathom layer)

after the maximum of the air-temperature was 49 days in 1886, and 36 in 1887; while for the bottom layer of ten fathoms it was 70 in 1886, and 80 days in 1887; an average of 42 for surface and 75 for bottom retardation. The retardation for the deep water was less than half as great as for the same depth in Loch Goil, 60 per cent. shorter than for

TABLE LX.—*Average Change of Temperature* per diem *in Dunoon Basin.*

Date.	No. of Days. Interval.	Mass of Water.	0–10 fms.	10–20 fms.	20–30 fms.	30–40 fms.	40–50 fms.	Over 50 fms.
19.6.86	62	+0·059	+0·081	+0·048	+0·040	+0·040	+0·040	+0·045
6.8.86	48	+0·074	+0·065	+0·080	+0·081	+0·081	+0·081	+0·066
26.9.86	51	+0·067	+0·041	+0·081	+0·086	+0·086	+0·080	+0·086
12.11.86	47	−0·038	−0·054	−0·034	−0·023	−0·017	−0·008	−0·010
24.12.86	42	−0·110	−0·115	−0·111	−0·104	−0·097	−0·097	−0·098
6.2.87	44	−0·059	−0·059	−0·054	−0·060	−0·066	−0·067	−0·062
24.3.87	52	−0·009	+0·003	−0·016	−0·017	−0·019	−0·019	−0·017
7.5.87	45	+0·035	+0·057	+0·025	+0·017	−0·013	−0·014	−0·015
14.6.87	38	+0·105	+0·139	+0·103	+0·069	+0·057	+0·052	+0·053
7.8.87	44	+0·116	+0·109	+0·125	+0·120	+0·110	+0·106	+0·103
30.9.87	54	0·000	−0·030	+0·003	+0·035	+0·052	+0·056	+0·055
30.11.87	61	−0·094	−0·100	−0·090	−0·091	−0·091	−0·090	−0·090
11.2.88	73	−0·053	−0·051	−0·059	−0·053	−0·052	−0·052	−0·053
8.3.88	25	−0·013	+0·001	−0·023	−0·023	−0·019	−0·017	−0·007
28.3.88	20	−0·086	−0·112	−0·064	−0·070	−0·079	−0·088	−0·093
Average Heating	...	+0·074	+0·062	+0·066	+0·064	+0·071	+0·069	+0·068
Times	...	6	8	7	7	6	6	6
Average Cooling	...	−0·058	−0·074	−0·056	−0·055	−0·050	−0·050	−0·049
Times	...	8	7	8	8	9	9	9
Average Change	...	0·065	0·068	0·061	0·059	0·058	0·058	0·051

Loch Fyne, and 40 per cent. shorter than for Loch Strivan; the obvious explanation being the much greater freedom of circulation in the Dunoon Basin than in the enclosed lochs. In other words, change of temperature throughout the mass is carried on more by mixture than by conduction.

The dates of the minimum and maximum temperature of the whole mass of water, and the temperatures at those epochs, as deduced from the curves, were as follows :—April 15th, 1886, 42°·0; September 22nd, 1886, 52°·6; March 15th, 1887, 43°·4; September 1st, 1887, 55°·0; and April 15th, 1888, 42°·0. The duration of warming in days, and the average rate of gain of temperature in degrees per day in the mass of the water, were as in Table LXI.

TABLE LXI.—*Period of Heating and Cooling and Daily Rate of Change of Temperature in Dunoon Basin.*

Heating, 1886.	Rate per day.	Cooling, 1886–87.	Rate per day.	Heating, 1887.	Rate per day.	Cooling, 1887–88.	Rate per day.
160	+0°·066	174	−0°·053	170	+0°·070	227	−0°·57

This approaches the distribution in the Arran Basin and Loch Strivan. The average number of days of heating was 165, and of cooling 200; the ratio of the time of heating to time of cooling being 100 : 121. The Channel and the Gareloch are the only other divisions in which the time of cooling approached the same high figure; in the Arran Basin the periods of heating and cooling were the same, and in the loch basins heating was the process requiring more time. As shown in Table LX. the average rate of heating was 0°·074 per day, and the average rate of cooling 0°·058; in other words, it required on the average 13½ days to raise the temperature of the mass of water 1°, and 17 days to lower it by the same amount. The rate of change of temperature decreased very slightly with increasing depth.

The air was warmer than the surface layer of 5 fathoms for 165 days in 1886, and for 120 in 1887, or an average of 143, while it was colder for 210 days in 1886–87, and

TABLE LXII.—*Mean Annual Temperature of Air and Water for the Dunoon Basin.*

Year.	I. Air. Mean for Area.	II. Air. Mean for Rothesay and Greenock.	III. Water. 0 – 5 fms.	IV. Water. Mass.	Difference. Air II. and Water III.	Difference. Air II. and Water IV.
1886	46·2	46·0	46·9	46·6	−0.9	−0·6
1887	47·0	47·2	48·8	48·5	−1·6	−1·3
Mean . . .	46·60	46·60	47·37	47·07	−1·25	−0·95

for 225 days in 1887–88, averaging 217 for the two years, nearly the same as for the other divisions.

By interpolating the values for the first three months of 1886, the mean annual temperatures of air and water may be compared as taken from the curve. The figures are given in Table LXII.

Next to Loch Strivan (0°·9), no other division of the Area showed so low an excess of surface water-temperature over the air as 1°·2. Gareloch and Loch Goil showed 1°·8, Arran Basin and Channel 1°·7, and Loch Fyne 1°·5. The difference is, however, very trifling, and may well lie within the limits of probable error. The surface water was practically of the same temperature as that of Loch Strivan, but the mass of water was 0°·3 warmer in the Dunoon Basin, or 0°·7 warmer than the mass of water in Loch Goil.

General Summary.

The scattered facts as to the thermal conditions of the Area are brought together in Tables LXIII. to LXVII., in order to make the similarities and contrasts between the various divisions more marked. The only omissions are in the cases of the Great Plateau, the Estuary, Loch Long, Loch Ridun and the Kyles of Bute, and the Holy Loch. For the treatment of these there were either insufficient data, or no prospect of finding results materially different from those for the similar divisions which have been critically considered. All the figures in the tables are not equally trustworthy: the method by which they were obtained is fully explained, and their relative value indicated under the heads of the respective divisions. Table LXIII. gives an approximation to the monthly mean temperature of the superficial 5 fathoms of water, calculated from the seasonal curves of each of the seven divisions which are considered. The Gareloch was, speaking generally, the warmest from May to September, and the coldest from October to April. Its slight depth and land-locked character, and its exposure to the extreme changes of temperature in the Estuary, combine to make it the most responsive to changes in seasonal heating or cooling power. The Channel, in which oceanic influences predominate over solar, was usually the warmest division from October to March, when winter cooling was most active everywhere. During the summer months of 1887, the Channel was colder than any other division, but at the same season in 1886, and probably in 1888 also, the lowest surface temperatures were found either in Loch Fyne or Loch Goil.

The month of minimum surface temperature was usually the same in all the divisions, and was April in 1886, March in 1887, and in 1888 both March and April. At this season the surface temperature was nearly the same over the whole Area, the greatest difference between the divisions being under 1°·5. The month of maximum in 1886 was September for the Channel and Gareloch, and October for the other divisions. In 1887 it was August for the Gareloch, and September for the rest, and in 1888 it was September for all the places where observations were made. The period of greatest

TABLE LXIII.—*Monthly Mean Temperature of Surface 5-Fathom Layer in the Divisions of the Clyde Sea Area, from Curves.*

1886.

Division.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Channel, . .	...	...	...	42·1†	44·6	47·5	50·1	52·8	55·0*	52·1	50·2*	49·0*
Arran Basin, .	...	...	...	43·5*	45·1	47·2	51·0	53·2	53·6	51·9	49·3	46·6
Dunoon Basin,	...	...	...	42·4	44·5	47·7	50·0	51·6†	53·2	52·0	49·5	45·1
Loch Strivan, .	...	...	...	42·4	44·4	47·1	50·0	52·5	54·0	52·0	49·0	46·3
Loch Fyne, . .	...	...	...	42·2	44·2†	46·8†	50·0	53·0	53·0	50·7†	48·3†	45·4
Loch Goil, . .	...	...	...	43·1	44·7	47·2	49·8†	51·6†	52·2†	51·6	49·8	46·6
Gareloch, . .	...	...	...	43·0	45·6*	48·7*	52·0*	53·5*	53·8	52·6*	49·2	44·6†
Mean, . .	...	...	...	42·7	44·7	47·5	50·4	52·6	53·5	51·8	49·3	46·2
Change of temp.	...	...	...	+2·0	+2·8	+2·9	+2·2	+0·9	−1·7	−1·5	−3·1	−2·2
Range between highest (*) and lowest (†), .	...	...	...	1·4	1·4	1·9	2·2	1·9	2·8	1·9	1·9	4·4

1887.

Division.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Channel, . .	47·2*	44·6*	44·1*	44·8	46·0†	48·4†	51·6†	55·3	55·9*	54·0*	51·4*	48·2*
Arran Basin, .	44·2	42·9	42·9	45·2*	48·0	51·8	54·4	55·2	55·2	53·8	50·8	47·0
Dunoon Basin,	43·0	42·5	42·8	44·4	47·2	51·6	55·2	56·8	55·3	52·4	48·6	46·0
Loch Strivan, .	43·6	41·5†	42·6	44·6	46·8	50·4	53·5	55·8	54·8	52·2	50·0	47·2
Loch Fyne, .	44·0	43·7	43·9	45·2*	47·8	50·8	53·2	54·4†	54·0†	52·4	49·0	45·3
Loch Goil, . .	43·6	42·1	42·7	45·1	48·1*	51·0	55·0	57·5	55·6	51·8	48·2	46·3
Gareloch, . .	42·8†	42·3	42·4†	44·2†	47·3	52·0*	56·8*	58·0*	55·6	51·5†	47·2†	44·8†
Mean, . .	44·0	42·8	43·0	44·8	47·3	50·9	54·2	56·1	55·2	52·6	49·3	46·4
Change of temp.	−1·2	+0·2	+1·8	+2·5	+3·6	+3·3	+1·9	−0·9	−2·6	−3·3	−2·9	−1·4
Range between highest (*) and lowest (†), .	4·4	3·1	1·7	1·0	2·1	3·6	5·2	3·6	1·9	2·5	4·2	3·4

1888.

Division.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Channel, . .	46·4*	44·3	43·2	42·9	43·8	...	...	...	...	...	...	...
Arran Basin, .	44·1	42·9†	42·4	42·8	...	...	...	...	...	...	...	...
Dunoon Basin,	45·6	44·5*	43·6*	43·3	...	...	...	...	...	...	...	...
Loch Strivan, .	45·2	44·1	42·8	43·6	46·0	48·8	51·8	54·4	54·9	52·0	...	...
Loch Fyne, .	44·4	44·0	43·1	43·3	45·0	47·6	50·0	52·2	53·2	...	...	...
Loch Goil, . .	45·5	44·3	42·9	44·5*	47·1	49·5	52·0	54·0	54·7	53·1	...	...
Gareloch, . .	43·9†	43·3	42·0†	42·2†	44·8	48·8	52·4	55·2	55·0	...	...	...
Mean, . .	45·0	43·8	42·9	43·2	...	...	...	...	...	...	...	...
Change of temp.	−1·2	−0·9	+0·3		...	...	...	...	...	...	...	...
Range between highest (*) and lowest (†), .	2·5	1·6	1·6	2·3	...	...	...	...	...	...	...	...

difference between the surface temperature of different divisions was at or immediately before the maximum. Thus, in September 1886 the surface water in the Channel was 6°·2 warmer than in Loch Goil, and in August 1887 that in the Gareloch was 7°·6 warmer than in Loch Fyne. Comparing the years under observation, we find that in 1887 the monthly temperature corresponded during the warming period with that two months later in 1886, and the maximum was on the average 2° higher. This was brought about by the spring minimum of 1887 being 1°·6 higher than in 1886 (0°·7 higher than in 1888), and by the increment of temperature between April and May being 1° greater, the succeeding monthly increments being a trifle less. The fall of temperature in 1887, between September and October, was 1°·4 greater than in 1886, so that the averages for the succeeding six months in both years were nearly the same.

The great feature of 1887, as regards surface temperature, was the rapid heating of early summer, leading to a higher surface maximum by bringing it on while the air temperature was still high, so that when the air-temperature began to fall it very speedily stopped farther heating. I have already shown, by reference to the invariable character of the surface temperature curve being cut at its maximum by the air-temperature curve, that the more rapid the rate of heating, the higher is the limiting temperature reached, while the slower the rate, even when much longer continued, the lower is the ultimate maximum. Hence, in the warmest years for surface water, the retardation of the surface after the air maximum is the least, and the greater the retardation the lower is the maximum. The whole may be put tersely in the words, that for all parts of the Clyde Sea Area the surface water continues to heat until its temperature reaches that of the air; as soon as this occurs surface-cooling sets in.

Table LXIV. gives the monthly mean temperature of the mass of water in each division calculated from the curves. This is not such a readily comparable datum as the surface temperature, because of the difference in the average depth of the various basins and in their degree of isolation. In its figures we may, however, look for satisfactory evidence as to the influence of configuration on temperature. The minimum mass temperature occurred in April 1886, in March 1887, and in March or April 1888, thus coinciding in time with the minimum of the surface layers. The warmest month for the mass of water was September in the Channel and the Gareloch, October for all the other divisions in 1886; August in the Gareloch and September in all the other divisions for 1887, this again corresponding to the date of surface maximum. The correspondence with surface changes is similarly shown by the fact that the Gareloch is the warmest division in summer and the coldest in winter; while the Channel is the warmest in winter, and Loch Fyne or Loch Goil usually the coldest in summer. From January to April 1888 Loch Fyne and Loch Goil were the warmest, their temperature being 1° higher than the Channel in February. While the greatest range between the warmest and coldest division as regards surface temperature was 5°·2, and the least 1°·0; the greatest range in mass temperatures was as much as 7°·6, and the least only 0°·5. At, or immediately after, the minimum the mass of water in the various divisions was most nearly uniform

TABLE LXIV.—*Monthly Mean Temperatures of the Mass of Water in the Divisions of the Clyde Sea Area, from Curves.*

Division.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1886.												
Channel, . .	...	...	...	42·1	44·6*	47·5	50·1	52·8	55·0*	52·1	50·2	49·0*
Arran Basin, .	...	...	...	42·3*	43·5	45·3	47·7	49·9	51·3	51·4	49·7	46·7
Dunoon Basin, .	...	...	...	42·2	43·0	45·4	48·1	50·0	52·2	52·4	50·5*	45·8
Loch Strivan, .	...	...	...	42·0	42·8†	44·8	47·6	50·0	51·9	52·4	50·2	47·3
Loch Fyne, .	...	...	...	42·0	42·8†	44·3†	46·0†	48·4	49·6	49·6	49·1†	47·6
Loch Goil, . .	...	...	...	41·8†	43·1	44·4	46·0†	47·6†	48·8†	49·5†	49·2	47·5
Gareloch, . .	...	...	...	41·9	44·4	48·3*	51·6*	53·5*	54·0	52·6*	49·4	45·2†
Mean, . .	...	...	...	42·0	43·5	45·7	48·1	50·3	51·8	51·4	49·8	47·0
Change of temp.	...	...	...	+1·5	+2·2	+2·4	+2·2	+1·5	−0·4	−1·6	−2·8	−1·9
Range between highest (*) and lowest (†), .	...	...	...	0·5	1·8	4·0	5·6	5·9	6·2	3·1	1·4	3·8
1887.												
Channel, . .	47·2*	44·6	44·1*	44·8*	46·0	48·4	51·6	55·3	55·9	54·0*	51·4*	48·2*
Arran Basin, .	44·5	43·7	43·5	44·4	46·2	48·4	50·2	52·0	52·1	50·4†	48·5	46·3
Dunoon Basin, .	44·4	43·5	43·4	43·7†	45·6	49·0	52·6	54·6	54·8	52·9	50·0	47·5
Loch Strivan, .	44·7	43·4	43·4	44·2	45·4	48·5	50·8	52·4	53·2	52·6	51·0	47·8
Loch Fyne, . .	45·6	44·5	43·8	44·4	45·6	47·6	49·2†	50·4†	51·2†	50·8	49·6	47·6
Loch Goil, . .	46·0	44·8*	43·9	44·2	45·2†	47·3†	50·0	52·7	52·8	51·1	49·4	47·9
Gareloch, . .	43·2†	42·6†	42·8†	44·1	46·8*	51·2*	56·0*	58·0*	56·0*	51·2	47·4†	45·5†
Mean, . .	45·1	43·9	43·6	44·3	46·8	48·6	51·5	53·6	53·7	51·9	49·6	47·2
Change of temp.	−1·2	−0·3	+0·7	+2·5	+1·8	+2·9	+2·1	+0·1	−1·8	−2·3	−2·4	−1·6
Range between highest (*) and lowest (†), .	4·0	2·2	1·3	1·1	1·6	3·9	6·8	7·6	4·8	3·6	4·0	2·7
1888.												
Channel, . .	46·4	44·3	43·2	42·9	43·8	...	...	...	...	...	...	...
Arran Basin, .	44·8	43·4†	42·3	42·8	...	...	...	...	...	...	...	...
Dunoon Basin, .	45·4	44·4	43·5	42·2	...	...	...	...	...	...	...	...
Loch Strivan, .	45·6	44·4	43·0	43·1	44·2	46·4	48·8	50·9	52·1	51·6	...	...
Loch Fyne, . .	46·0	45·4*	43·6*	43·6*	44·2	46·0	47·2	48·2	48·7	...	...	...
Loch Goil, . .	46·7*	45·4*	43·6*	43·6*	44·5	45·9	47·5	49·2	50·9	50·5	...	...
Gareloch, . .	44·1†	43·6	42·2†	42·1†	44·0	48·0	51·6	54·2	54·8	...	...	...
Mean, . .	45·6	44·4	43·1	42·9	...	...	...	...	...	...	...	...
Change of temp.	−1·2	−1·3	−0·2		...	...	...	...	...	...	...	...
Range between highest (*) and lowest (†), .	2·6	2·0	1·4	1·5	...	...	...	...	...	...	...	...

in temperature, the greatest diversity occurring at or before the maximum. Thus in July and August 1886 the Gareloch was 5°·6 and 5°·9 warmer than Loch Goil, and in September the Channel was 6°·2 warmer than Loch Goil. In July and August 1887 the Gareloch was 6°·8 and 7°·6 warmer than Loch Fyne, and about 6° warmer than the Arran Basin, the influence of depth and isolation showing itself to the full.

TABLE LXV.—*General Summary of Temperature Conditions in the Clyde Sea Area.*

		Air.	Water.							
		Mean for Area.	Channel.	Arran Basin.	Dunoon Basin.	Loch Strivan.	Loch Fyne.	Loch Goil.	Gareloch.	Mean.
1.	Mean annual surface temperature, 1886	46·2	48·2	47·4	46·9	47·0	46·8	47·1	47·5	47·3
2.	,, ,, 1887	47·0	49·3	49·3	48·8	48·6	48·6	48·9	48·7	48·9
3.	,, ,, 1888	47·3	...	...	...	48·2	47·1	47·9	47·6	...
4.	,, ,, 1886–87	46·6	48·7	48·3	47·8	47·9	47·7	48·0	48·1	48·2
5.	Mean range, max. to min., 1886–87	20·7	12·3	11·2	12·5	12·9	10·8	12·3	13·3	12·2
6.	Mean annual mass temperature, 1886	...	48·2	46·4	46·6	46·4	45·8	45·7	47·4	...
7.	,, ,, 1887	...	49·3	47·5	48·5	48·1	47·5	47·9	48·7	...
8.	,, ,, 1888	...	...	...	...	47·3	46·0	47·1	47·5	...
9.	,, ,, 1886–87	...	48·7	46·9	47·1	47·3	46·6	46·8	48·1	47·3
10.	Mean range, max. to min., 1886–87	...	12·3	8·8	10·8	10·1	7·5	8·3	13·7	10·2
11.	Excess surface over local air, 1886	...	1·7	1·2	0·9	0·6	1·3	1·1	1·0	1·1
12.	,, ,, 1887	...	1·7	2·3	1·6	1·2	1·7	2·5	2·8	2·0
13.	,, ,, 1888	...	...	...	...	1·3	0·5	1·0	0·3	...
14.	,, ,, 1886–87	...	1·7	1·7	1·3	0·9	1·5	1·8	1·9	1·5
15.	Days air warmer than surface, 1886	...	150	147	165	164	165	172	154	160
16.	,, ,, 1887	...	105	125	120	126	120	104	94	113
17.	,, ,, 1888	...	...	...	...	134	150	132	155	...
18.	,, ,, 1886–87	...	134	136	143	145	143	138	124	137
19.	Days air colder than surface, 1886	...	244	224	210	220	216	224	245	226
20.	,, ,, 1887	...	230	232	225	230	222	248	250	234
21.	,, ,, 1886–87	...	237	228	217	225	219	236	248	230
22.	Retarda. surf. max. after air, days, 1886	...	48	48	49	45	45	66	54	51
23.	,, ,, 1887	...	46	46	36	39	50	42	30	41
24.	,, ,, 1888	...	...	...	...	...	35 (?)	20 (?)	20 (?)	...
25.	,, ,, 1886–87	...	47	47	42	42	48	54	42	46
26.	Retarda. 30–40 fms. max. after air, 1886	...	48	52 (?)	70	105	126	180	...	...
27.	,, ,, 1887	...	46	50 (?)	80	119	120	150	...	...
28.	,, ,, 1886–87	...	47	51 (?)	75	112	123	165	...	89 (?)
29.	Mean daily rate of mass-heating, 1886	0·122	0·090	0·058	0·066	0·060	0·047	0·038	0·081	...
30.	,, ,, 1887	0·125	0·065	0·046	0·070	0·049	0·037	0·058	0·107	...
31.	,, ,, 1888	0·125	...	...	...	0·050	0·033	0·043	0·079	...
32.	,, ,, 1886–87	0·124	0·078	0·052	0·068	0·054	0·042	0·048	0·094	0·062
33.	Mean daily rate of mass-cooling, 1886	0·098	0·065	0·053	0·053	0·059	0·039	0·040	0·070	...
34.	,, ,, 1887	0·094	0·062	0·049	0·057	0·052	0·045	0·046	0·064	...
35.	,, ,, 1886–87	0·096	0·064	0·051	0·055	0·056	0·042	0·043	0·067	0·054
36.	Mean days cooling per 100 of heat, 1886	106	116	92	109	86	93	73	108	97
37.	,, ,, 1887	145	115	107	133	98	89	131	173	121
38.	,, ,, 1886–87	125	115	100	121	93	91	99	130	109

In Table LXV. the annual periods of temperature change are compared for the various divisions, the data being in each case taken from the curves and detailed tables which have already been fully discussed. The mean annual range, Nos. 5 and 10, is the difference between the monthly temperature for the coldest and warmest month of the year, as detailed in Tables LXIII. and LXIV. The values relating to surface conditions, and to those connecting surface and air, are averaged in the last column, as the air and surface layer of water being each continuous over all the divisions, may be looked on as parts of

one whole, and the averages may, accordingly, be accepted as approximately true for the Area as a whole. The mass temperatures for each year are not meaned, as the difference in the depth of the divisions deprives them of comparative value, and the same holds good for the retardation of temperature at great depths. The mean of the 1886–87 average is given as a rough datum for comparison in all cases, even where it would require to be modified by weighting for difference in depth and volume in order to be truly comparable.

Looking first at the general results for the two years 1886 and 1887, we find that the air-temperature in 1887 was 0°·8 higher than the previous year, while the temperature of the superficial 5 fathoms was 1°·3 higher; and, taking account of the relation of surface temperature to local air-temperature for each division, the excess of surface water over air temperature was twice as great in 1887 as in 1886, *i.e.*, 2° as compared with 1°·1. The contrast between the two years was greatest in summer, and is best shown in the rapidity with which the surface temperature rose in 1887, the maximum being reached only 41 days after the air maximum, as compared with 51 days in 1886. Since it has been shown that the curve of surface water temperature rises until it is cut by the descending curve of air-temperature, rapid heating means a high surface maximum, and explains the somewhat curious fact that in 1887, the year of high water-temperature, the air was warmer than the water for 113 days only, as compared with 160 in 1886; and that in 1887 the period of mass-cooling of the water was 21 per cent. longer than that of heating, whereas in 1886 it was 3 per cent. shorter. Put briefly, the contrasted temperature results of the two years indicate that the longer the duration of heating in surface water the lower is the ultimate maximum, or that the rate of heating is proportional to the amount of heating.

The range of temperature between the coolest and warmest months was, on the average of the two years, 20°·7 for the air, 12°·2 for the superficial 5 fathoms of water, and 10°·2 for the whole mass of water, thus indicating that sea-water in layers, averaging 30 fathoms deep, is just half as responsive to temperature changes as the air at the Earth's surface; while layers 5 fathoms deep, when resting on deeper water, are 60 per cent. as responsive as the surface air. The same result as to mass-heating is brought out by comparing the mean daily rate of seasonal heating and cooling, this being practically half as great in the water as in the air.

Arranging the various divisions with reference to the difference of their data from those of the Channel, we are able to get a hint as to the modifying influence of depth and isolation. When this is done for the seven different elements of surface temperature, mass temperature, excess of surface over air temperature, surface retardation of maximum, retardation of maximum at 35 fathoms, rate of change of temperature in the mass, and proportion of time of cooling to that of heating, and the numeral expressing the position of the division in the series, the Channel being taken as zero, is written after its name: the sum of the numbers in each case would tend to approach equality if the order were merely accidental. If a well-defined order appears it cannot be accidental, but must

point to some definite cause. Gareloch came first 5 times and second once, out of the six columns in which it appeared, its total being 7. This is interesting in showing how the thermal changes in a shallow, brackish, and nearly land-locked basin were almost the same in order and amount as those of the freely-exposed Channel, where the complete mixture of water by currents entirely neutralised the evidence of depth, and the free communication with the ocean seemed to make up for the reduced effect of radiation on a clear water surface remote from land. Arran Basin came first on 2 occasions, third on 2 occasions, and fourth 3 times, the total being 20. Dunoon Basin, with a total of 21, may be taken as practically the same. It was never first, but was second on 4 occasions, third on 1, and fifth on 2. Loch Strivan had a total of 26, Loch Goil of 30, and Loch Fyne of 37. In the last case the position was fourth on 2 occasions, fifth on 1, and sixth 4 times. The order of restricted range, retarded phase, and lowered mean temperature is thus, following the Channel :—

1. Gareloch.
2. { Arran Basin. / Dunoon Basin.
4. Loch Strivan.
5. Loch Goil.
6. Loch Fyne.

Depth is obviously a factor of some importance, or Gareloch would not come first, but it is a factor of very minor importance, or Arran Basin would not come second. The order of the larger basins and deeper lochs is obviously that of the degree of isolation due to configuration of the basin, not alone to height of barrier, but to number of barriers, or Loch Goil would not come before Loch Fyne.

The contrast between the Gareloch and Loch Fyne is very marked—comparing them, the former is found 0°·5 warmer on the surface, 1°·5 warmer in its mass, with a surface range between the extreme months 2°·5 greater, and a range in mass temperature 6°·2 greater (almost double), with an average rate of change of seasonal temperature twice as great, and with its period of cooling, compared with that of heating, nearly 40 per cent. longer.

Heat Transactions of the Clyde Sea Area.—So far the discussion has been limited to changes of temperature, because to compare the actual amounts of heat involved in the various transactions would be difficult without fuller evidence as to transverse sections, and as to the specific heat of sea-water of different salinity. A few preliminary calculations were made which may be placed on record, although they are but a rough approximation. According to Professor THOULET of Nancy,* if the specific heat of pure water is taken, as unity, that of sea-water of density ($_4S_{15\cdot56}$) 1·00159 is 0·986 ; for density 1·01162 it is 0·957, while for density 1·02666 it is 0·931. The formula for expressing the number of heat units in a mass of sea-water may be put as $V \times D \times \sigma(t-t')$, where V is the volume, D the density, σ the specific heat, and $t-t'$ the change of temperature.

* THOULET, *Oceanographie—Statique*, 1889, p. 298.

But for the range of density which has to be considered, the value of $D\sigma$ is practically a constant $=0{\cdot}96$ (range approximately from 0·959 to 0·961), and for the divisions under consideration, taking the volume of the Gareloch at half-tide as a convenient unit, we have the following values of $VD\sigma$, where V is in every case the volume at half-tide, expressed in units of the capacity of the Gareloch.*

Gareloch	$VD\sigma$	=	0·96	=	1
Loch Goil	„	=	1·42	=	1·48
Loch Fyne	„	=	18·52	=	19·29
Arran Basin	„	=	663·77	=	691·43

Table LXVI. gives the mean temperature of the mass of water in four divisions at the spring minima and autumn maxima, change of temperature, and the quantity of heat gained or lost, which is obtained by multiplying the change of temperature by the foregoing factors. The heat unit employed is the Gareloch-degree, or the amount of heat necessary to raise a mass of pure water equal to the half-tide contents of the Gareloch, from 32° to 33° F. Multiplying by 166,000,000 would give the value in ton-degrees, or multiplying by 371,840,000,000 would give it in Fahrenheit heat units.

TABLE LXVI.—*Total Heat Changes in the Water of the Clyde Sea Area.*

Division.	Min. 1886.	Max. 1886.	Change.	Heat gained.	Min. 1887.	Change.	Heat lost.	Max. 1887.	Change.	Heat gained.	Min. 1888.	Change.	Heat lost.
				G. L. Units.			G. L. Units.			G. L. Units.			G. L. Units.
Gareloch . .	41°·8	54°·1	12°·3	12·30	42°·7	11°·4	11·40	57°·9	15°·2	15·20	41°·9	16°·0	16·00
Loch Goil .	41·8	49·8	8·0	11·84	43·7	6·1	9·03	56·1	12·4	18·35	43·3	12·8	18·94
Loch Fyne .	42·0	49·9	7·9	152·39	44·3	5·6	108·02	51·4	7·1	136·96	44·4	7·0	135.03
Arran Basin .	42·0	51·6	9·6	6637·73	43·6	8·0	5531·44	52·2	8·6	5946·30	42·5	9·7	6606·87

It thus appears that Loch Goil, on account of its greater volume, has about the same thermal power as the Gareloch, although its range of temperature is very much less. Loch Fyne has about ten times the thermal power, and the Arran Basin 500 times the thermal power of the Gareloch. Taking the average of heat gained and lost in the two years into account, along with the area of each of the divisions considered, we see in Table LXVII. the actual thermal power per square mile, or the amount of heat stored or returned through each unit of area.

Taking roughly 5·5 Gareloch-degree units per square mile as the normal amount of heat exchange between successive maxima and minima, would give for the whole Area a total of 6403·8 units; but estimating 6 units as a more probable value for the transference per square mile, we would get 6985, or nearly 7000 units. Table LXVII.

* See Part I., *Trans. Roy. Soc. Edin.*

shows how the amount of transference of heat per square mile depends on the depth of the water, each square mile of the Arran Basin receiving and parting with nearly three times as much heat as a square mile of the Gareloch, supposing all the heat to enter and leave by the surface. Earlier discussions showed, however, that a large part of the heat in the seaward division of the Area came not from the sun but from the sea, hence it is probable that distance from the Channel and isolation as well as the shallow-

TABLE LXVII.—*Heat Storing Power of the Divisions of the Clyde Sea Area.*

Division.	Area.	Gareloch-Degrees.				Average Depth.	Average Axial Depth.
		Average Heat Stored, 1886–87.	Average Heat Returned, 1886–87.	Heat Stored per square Mile.	Heat Returned per sq. Mile.		
Gareloch, . . .	4·23	13·75	13·70	3·25	3·24	$7\frac{1}{2}$	18
Loch Goil, . . .	3·36	15·09	14·00	4·49	4·16	14	$30\frac{1}{2}$
Loch Fyne, . . .	28·44	144·67	121·52	5·08	4·27	$22\frac{1}{2}$	$40\frac{1}{2}$
Arran Basin, . .	685·00	6292·01	6019·15	9·18	8·78	34	68
TOTAL, C. S. A.,	1164·33	...	...	...	...	29	...

ness of the water have a good deal to do with reducing the surface heat transactions. The difference in depth between Lochs Goil and Fyne would suggest a greater difference in thermal power than is found, while the difference in depth between Loch Fyne and the Arran Basin would suggest a less difference than occurs, if depth were the only or the main agent in producing the difference. We are probably not far wrong in surmising that from one-half to two-thirds of the heat stored and lost by the Arran Basin is independent of local solar radiation, and depends entirely on tidal mixture with sea-water.

The total heat absorbed in a year and returned by the Clyde Sea Area must be equivalent to about 2,010,000,000,000,000,000 foot pounds. Taking a horse-power as 33,000 foot pounds per minute, the heat of the Clyde Sea Area, as it is given out from September to March, is equivalent if it were all turned into work to the performance of an engine of 3,700,000 horse-power.

It is interesting to notice that in 1887, notwithstanding the high maximum temperature, much less heat was stored than in 1886, the low minimum with which 1886 started accounting for the fact.

I do not profess to have exhausted my subject, for the observations would in several instances stand more rigorous treatment; but there are so many points in which farther

observations would be helpful or necessary that I think it best to postpone the more theoretical considerations until a time of greater leisure arrives, or a better-equipped physicist feels prompted to build on these foundations. My effort has been to suggest ways in which the data could be handled so as to draw from them only the general principles which they unmistakably suggest; and I believe that I have employed no theory in this process which could vitiate the resulting conclusions. If, in the endeavour to avoid error, I have failed to arrive at the whole truth, doubtless others bolder and more skilful wil lfind it worth their while to work over the unexhausted slag-heaps. May they be rewarded by much reducible ore!

CONTENTS AND SUMMARY OF PART III.—TEMPERATURE.

	PAGE
PRELIMINARY,	1–3
INSTRUMENTS AND METHODS,	3–13
Surface Temperature,	3
Deep Sea Thermometer,	4
Corrections,	4
The *Scottish* frame,	5
The "Medusa," and Equipments,	6
Table I. Mean Velocity of Fall of Brass Weights in Sea-Water,	7
Table II. Time Occupied by Brass Weights in Falling 10 Fathoms through Water,	8
Treatment of Temperature Results—	
Recording Observations,	8
Plotting Curves of Vertical Distribution,	9
Seasonal Temperature Curves,	9
Temperature Sections,	9
Calculation of Mass Temperature,	10
Time-Depth Temperature Diagrams,	10
Terminology Employed,	11
Types of Vertical Curves,	11
Table III. Mean Temperature of Air over Clyde Sea Area in 1886, 1887, 1888,	12
TEMPERATURE TRIPS,	13–31
Table IV. Stations where Observations of Temperature were made,	14
Description of Temperature Trips—	
1. April 1886,	15
2. June „	16
3. August „	17
4. September „	18
5. November „	19
6. December „	20
7. February 1887,	20
8. March–April „	21
9. May „	22
10. June „	23
11. July „	24
12. August „	25
13. September „	26
14. November–December „	27
15. December 1887–January 1888,	27
16. January „	27
17. February „	28
18. March „	28
19. March 1888,	29
20. April „	29
21. June „	30
22. August–September „	30
23. October „	31
General Result of the Trips,	31
THERMAL CONDITIONS OF THE DIVISIONS OF THE CLYDE SEA AREA,	31–149
The North Channel—	
Table V. Temperature Observations in the Channel,	32
Homothermic Character of the Channel,	33
Seasonal Change of Temperature in the Channel,	34
Table VI. Rate of Change of Temperature in the Channel,	36
The Great Plateau—	
Table VII. Temperature Observations on the Plateau (Eastern Side),	38
„ VIII. Rate of Change of Water-Temperature on the Plateau (Eastern Side),	38
„ IX. Temperature Observations on the Plateau (Western Side),	39
General form of Temperature curve,	39
Hourly Observations on Plateau,	41
The Arran Basin—	
Table X. Temperature Observations off Carradale,	46
„ XI. Temperature Observations off Loch Ranza,	47
„ XII. Temperature Observations off Largybeg,	47
„ XIII. Temperature Observations off Brodick,	48
Cross Sections in East Arran Basin,	48
Table XIV. Temperature Observations off Garroch Head,	51
„ XV. Rate of Change of Temperature off Garroch Head,	52
„ XVI. Average Daily Rate of Heating and Cooling off Garroch Head,	53

	PAGE
The Arran Basin—contd.	
Seasonal Change of Temperature, Garroch Head,	53
Table XVII. Temperature Observations in Inchmarnoch Water,	56
„ XVIII. Temperature Observations off Ardlamont Point,	56
„ XIX. Temperature Observations off Skate Island,	57
Rate of Daily and Hourly Temperature Change, Skate Island,	58
Cross Section at Skate Island,	60
Seasonal Temperature Changes at Skate Island,	61
Table XX. Typical Vertical Temperature Curves off Skate Island,	61
Relation of Density to Temperature Change,	63
Table XXI. Temperature Observations off Kilfinan Bay,	64
„ XXII. Temperature Observations at Otter I.,	65
Temperature Sections of the Arran Basin,	66
Particulars of 18 Axial Sections, Channel-Cuill,	66
Compound Sections, radiating from Inchmarnoch,	69
Seasonal Range of Temperature in Arran Basin,	70
Table XXIII. Monthly Mean Temperature of the Mass of Water in the Three Divisions of the Arran Basin, from Curves,	70
Loch Fyne—	
Table XXIV. Temperature Observations at Otter II.,	73
Surface Observations at Otter,	74
Table XXV. Temperature Observations off Gortans Pt.,	75
„ XXVI. Temperature Observations at Minard and Paddy Rock,	76
„ XXVII. Temperature Observations off Furnace,	77
„ XXVIII. Temperature Observations off Strachur,	79
„ XXIX. Temperature Observations off Inveraray,	80
Rate of Daily and Hourly Temperature Change at Strachur and Inveraray,	80
Cross Section at Inveraray,	82
Table XXX. Typical Vertical Temperature Curves in Loch Fyne,	83

	PAGE
Loch Fyne—contd.	
Seasonal Range of Temperature at Strachur and Inveraray,	83
Table XXXI. Temperature Observations at Dunderawe,	86
„ XXXII. Temperature Observations at Cuill,	88
Temperature Sections of Loch Fyne,	90
Particulars of 23 Sections,	90
Table XXXIII. Density of Water, *in situ*, in Loch Fyne,	92
„ XXXIV. Bottom Salinity and Temperature at Strachur,	98
Seasonal Variations of Temperature in the Mass of Water in Loch Fyne,	98
Table XXXV. Mean Temperature at Various Depths in Loch Fyne,	99
„ XXXVI. Average Change of Temperature *per diem* in Loch Fyne,	101
„ XXXVII. Mean Annual Temperature of Air and Water for Loch Fyne,	103
Gareloch—	
Table XXXVIII. Temperature Observations at Row I.,	104
„ XXXIX. Temperature Observations at Row II.,	105
„ XL. Cross Section of Gareloch at Clynder,	106
„ XLI. Temperature Observations at Shandon,	108
Typical Gareloch Temperature Curves,	108
Partial Cross Section at Shandon,	109
Table XLII. Temperature Observations at Garelochhead,	110
Temperature Sections of the Gareloch,	111
Particulars of 19 Sections,	111
Evidence as to Circulation of Gareloch,	115
Table XLIII. Mean Temperature of Vertical Soundings, Gareloch,	118
„ XLIV. Mean Temperature at Various Depths in the Gareloch,	118
„ XLV. Period of Heating and Cooling, and Daily Rate of Change of Temperature in the Clyde Sea Area,	120
„ XLVI. Mean Annual Temperature of Air and Water for the Gareloch,	121

PAGE

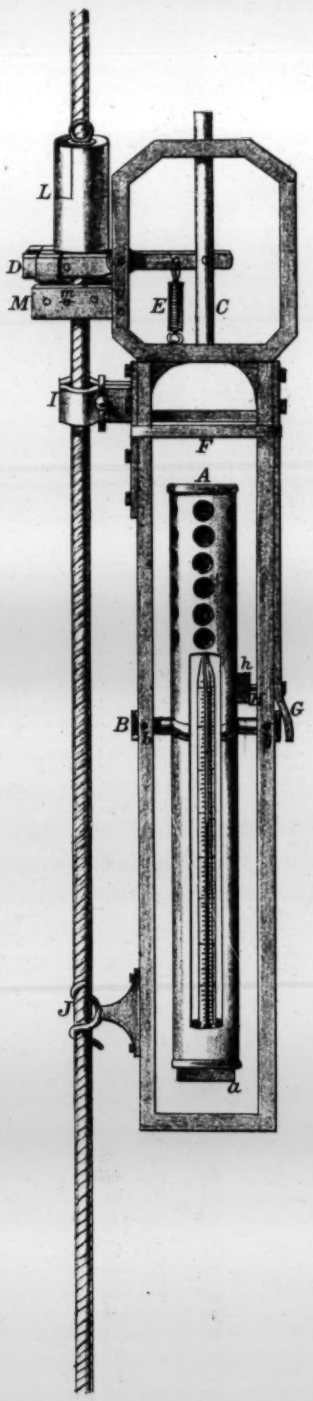
Loch Goil—
Table XLVII. Temperature Observations of Dog Rock, . 123
„ XLVIII. Temperature Observations at Loch Goilmouth, . . 124
Temperature Observations off Carrick Castle, ... 124
Table XLIX. Temperature Observations off Stuckbeg, . 125
„ L. Typical Vertical Temperature Curves, Stuckbeg, . . 126
„ LI. Temperature Observations at Loch Goilhead, . . 128
Temperature Sections of Loch Goil, . 128
Particulars of 17 Sections, . . 128
Table LII. Mean Temperature at Various Depths in Loch Goil, . . 132
„ LIII. Average Change of Temperature *per diem* in Loch Goil, . 134
„ LIV. Mean Annual Temperature of Air and Water for Loch Goil, 135
Loch Strivan—
Temperature Observations at Clapochlar, ... 136
Temperature Sections of Loch Strivan, Particulars of 23 Sections, . . 137
Seasonal Variation of Temperature, . 137
Table LV. Period of Heating and Cooling and Daily Rate of Change of Temperature in Loch Strivan, . . 141
„ LVI. Mean Temperature at Various Depths in Loch Strivan, . 142
„ LVII. Average Change of Temperature *per diem* in Loch Strivan, . 143
„ LVIII. Mean Annual Temperature of Air and Water for Loch Strivan, . 144

PAGE

The Dunoon Basin—
Comparison of Observations at Dog Rock and Gantock, . . . 145
Table LIX. Mean Temperature at Various Depths in Dunoon Basin, . 146
„ LX. Average Change of Temperature *per diem* in Dunoon Basin, . 147
„ LXI. Period of Heating and Cooling, and Daily Rate of Change of Temperature in Dunoon Basin, . 148
„ LXII. Mean Annual Temperature of Air and Water for Dunoon Basin, . 148
General Summary— 149–158
Temperature Conditions of the Clyde Sea Area, ... 149
Table LXIII. Monthly Mean Temperature of Surface 5-Fathom Layer in the Divisions of the Clyde Sea Area, . 150
„ LXIV. Monthly Mean Temperatures of the mass of Water in the Divisions of the Clyde Sea Area, 152
„ LXV. General Summary of Temperature Conditions in the Clyde Sea Area, . . 153
Thermal Classification of the Divisions, ... 155
Heat Transactions of the Clyde Sea Area, . 155
Specific Heat and Density of Sea-Water, ... 155
Table LXVI. Total Heat Changes in the Water of the Clyde Sea Area, . . 156
„ LXVII. Heat-storing Power of the Divisions of the Clyde Sea Area, . 157
Estimate of Heat Gained and Lost by the Area as a Whole, . . 158
Contents and Summary, . . . 159–161

NEGRETTI & ZAMBRA'S DEEP-SEA THERMOMETER IN THE SCOTTISH FRAME.

Fig. 2. *REVERSED.*



A Thermometer Case.

a Groove in top of case.

B Pivots on which case rotates.

b Set-screw to prevent pivots working loose.

C Pin holding case erect.

D Lever raising pin and letting thermometer reverse.

E Spiral spring keeping pin in place.

F Indiarubber band to start thermometer when pin is withdrawn.

G Flat brass spring.

H Point attached to *G* to secure thermometer in inverted position.

h Boss in which *H* fits.*

I Vice, securing thermometer frame to line.

J Ram's-horn attachment securing line to lower part of frame.

K Messenger suspended by wire to groove *a*.

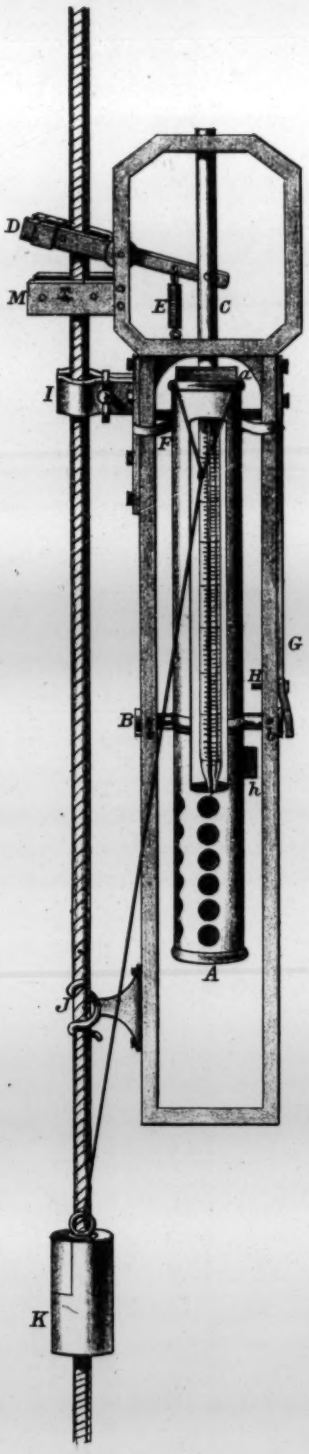
L Messenger from above striking *D*, which raises *C* and lets *A* reverse, *K* being cast loose to descend to next thermometer.

M Forked piece on which *D* rests, and through which the sounding line passes freely.

m Split pin to prevent sounding line slipping out of fork *M*.

* *The clamping arrangement shown here is now superseded by a more satisfactory form, devised by Messrs. Negretti & Zambra.*

Fig. 1. *SET.*



Soc Edin^r Vol. XXXVIII
Fig. 1

TEMPERATURE VARIATIONS

PLATE II

SKATE ISLAND. Arran Basin Central. DEPTH AND TIME.

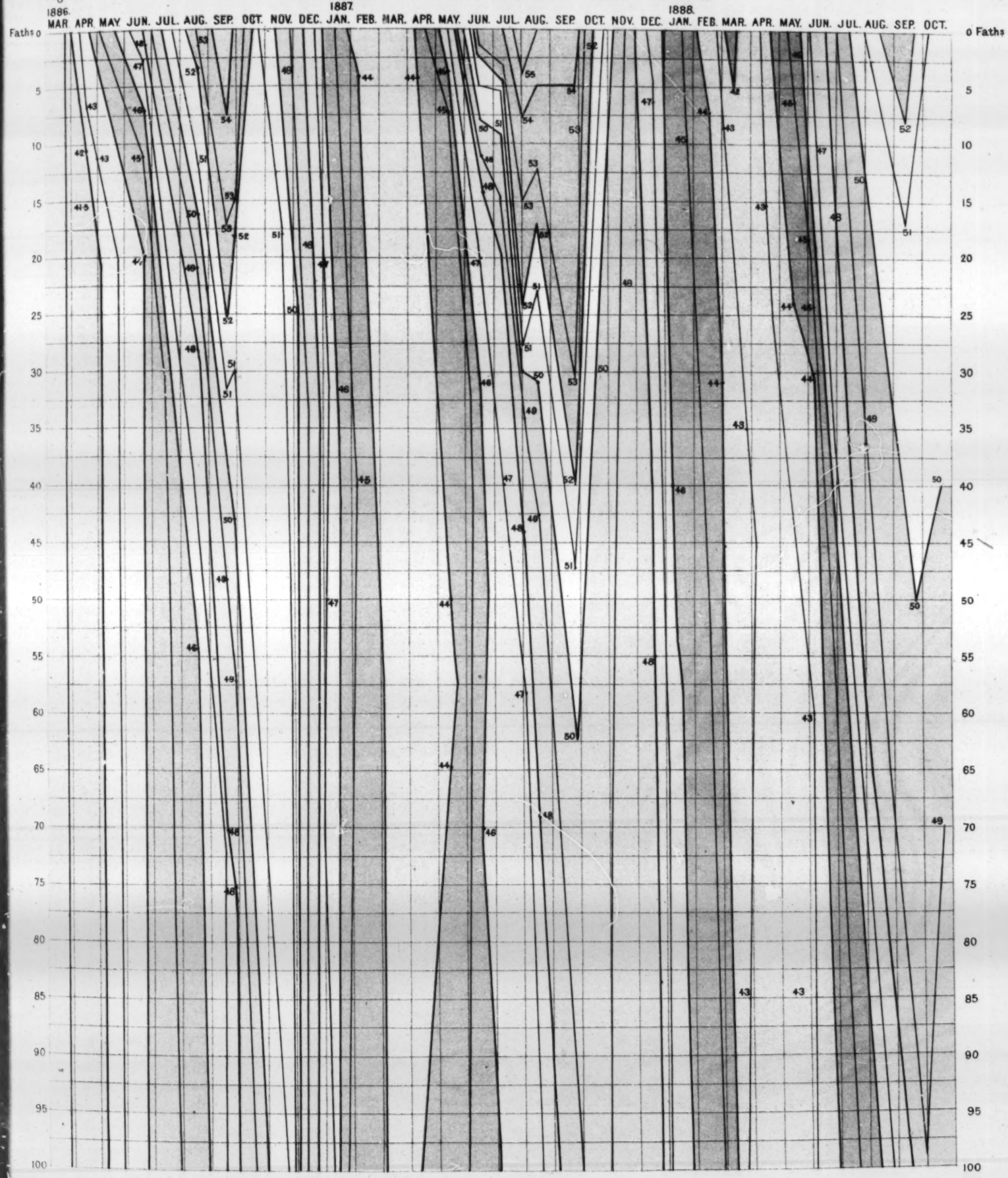
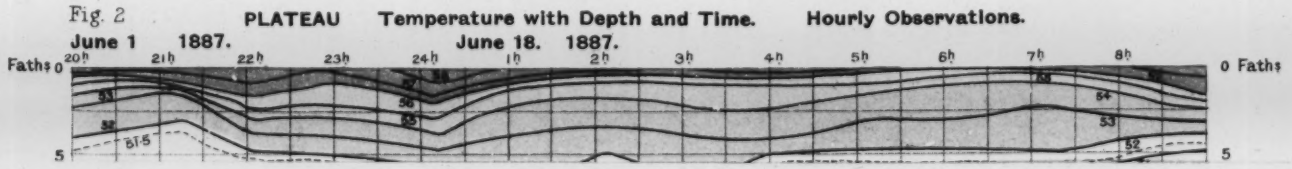


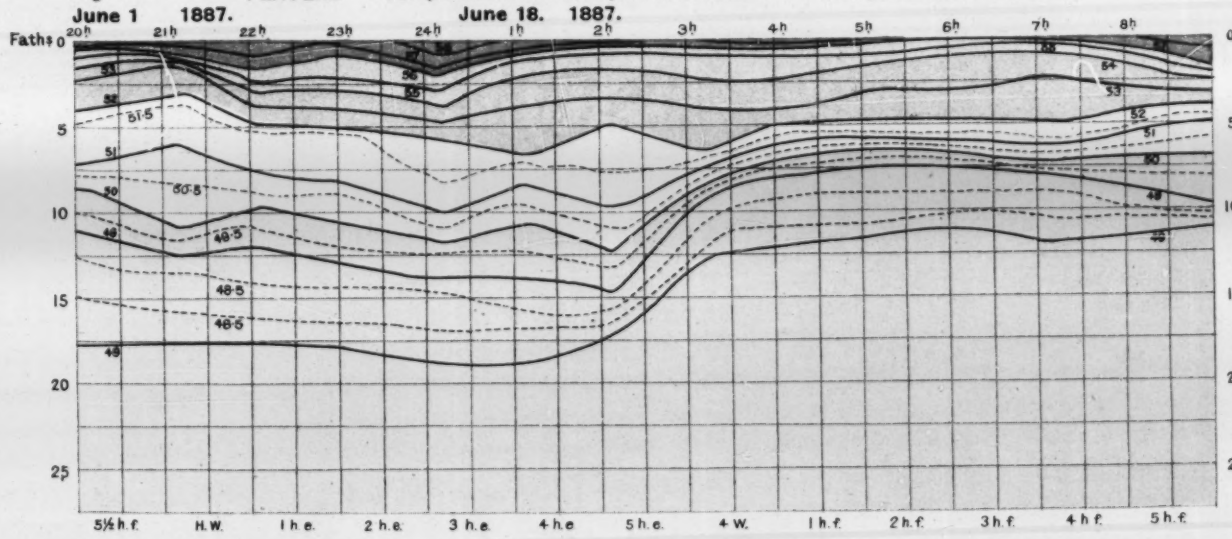
Fig. 2 PLATEAU Temperature with Depth and Time. Hourly Observations.



SCALE OF COLOURING FOR TEMPERATURE

Fig. 2 **PLATEAU Temperature with Depth and Time. Hourly Observations.**

June 1 1887. June 18. 1887.



Scale of Colouring for Temperature

Above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
Below 40°

Bartholomew, Edin.

TEMPERATURE VARIATIONS

Fig. 3

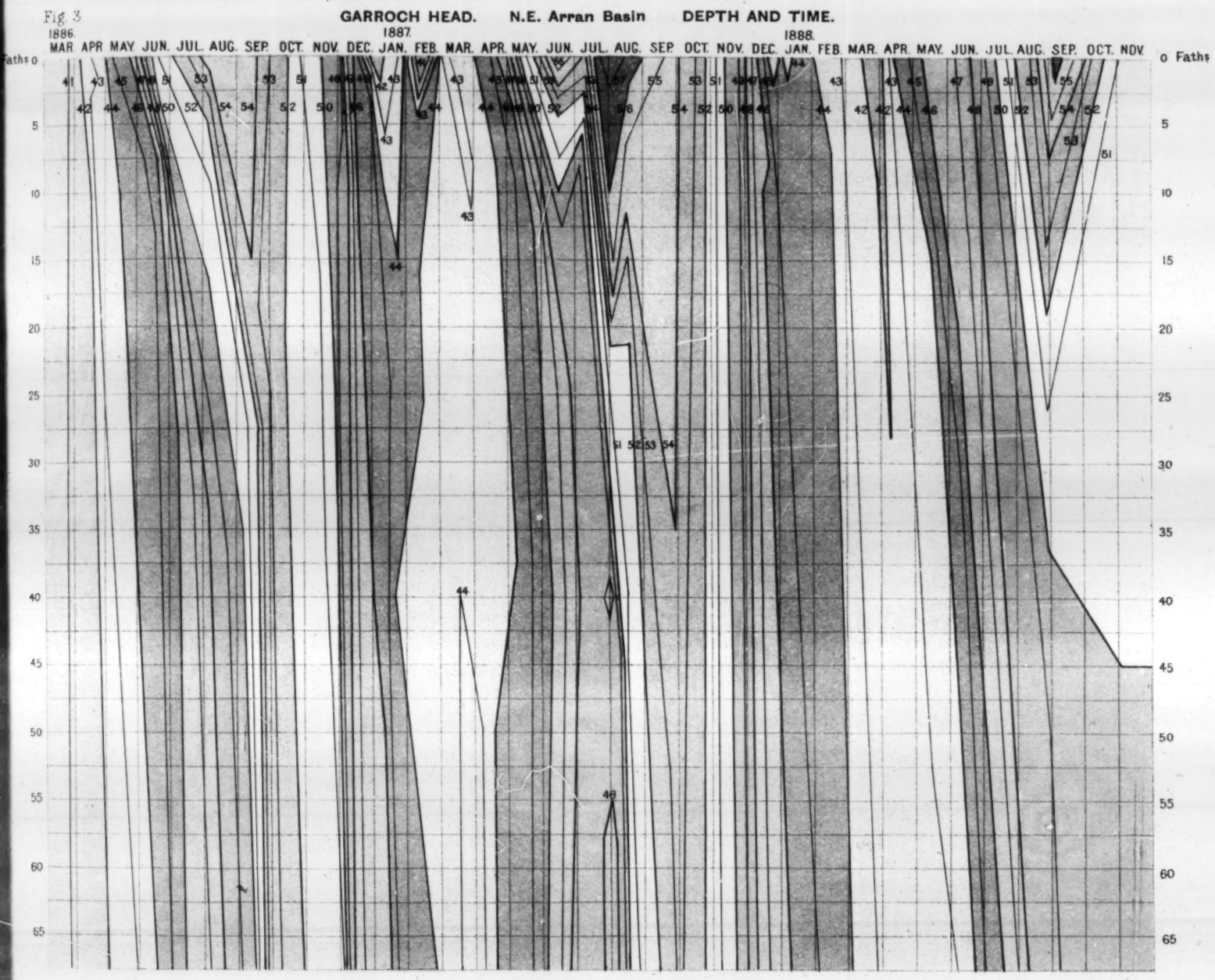
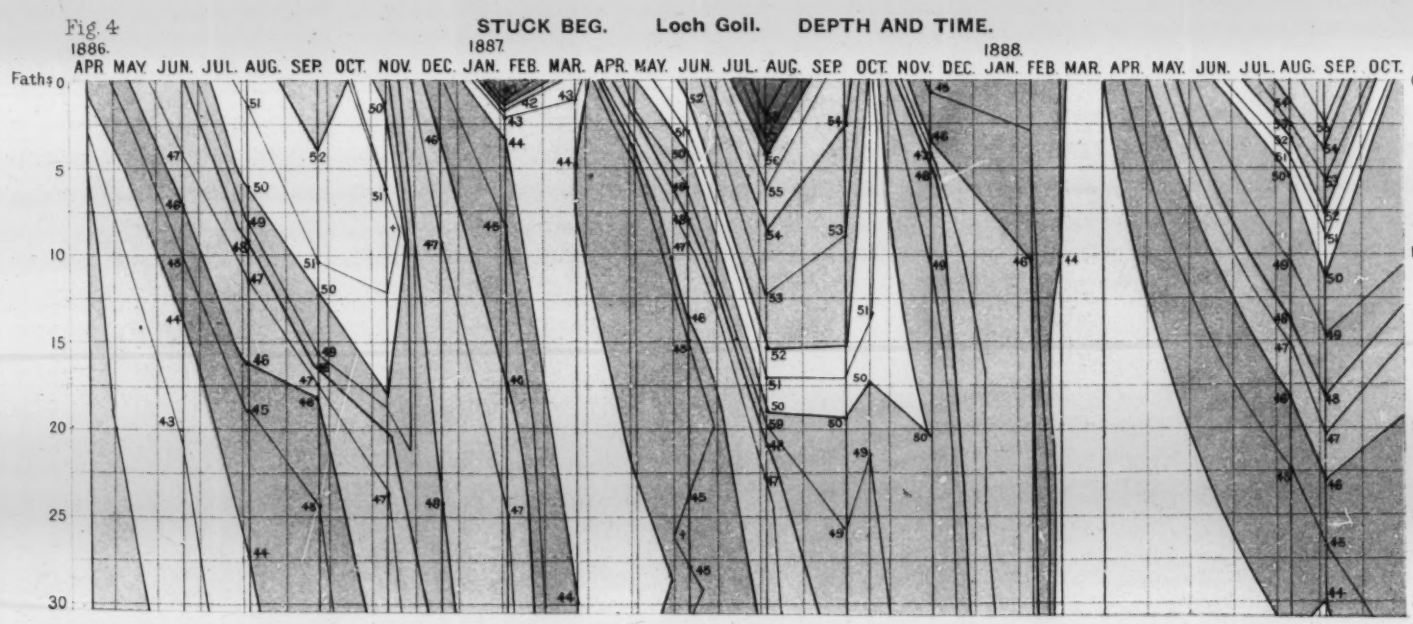


Fig. 4



SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°

Fig. 4

STUCK BEG. Loch Goil. DEPTH AND TIME.

1886. 1887. 1888.

APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT.

Faths 0 5 10 15 20 25 30 35 40 45 0 Faths

SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°
48° – 48°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
BELOW 40°

Bartholomew, Edin

TEMPERATURE VARIATIONS

Fig. 5

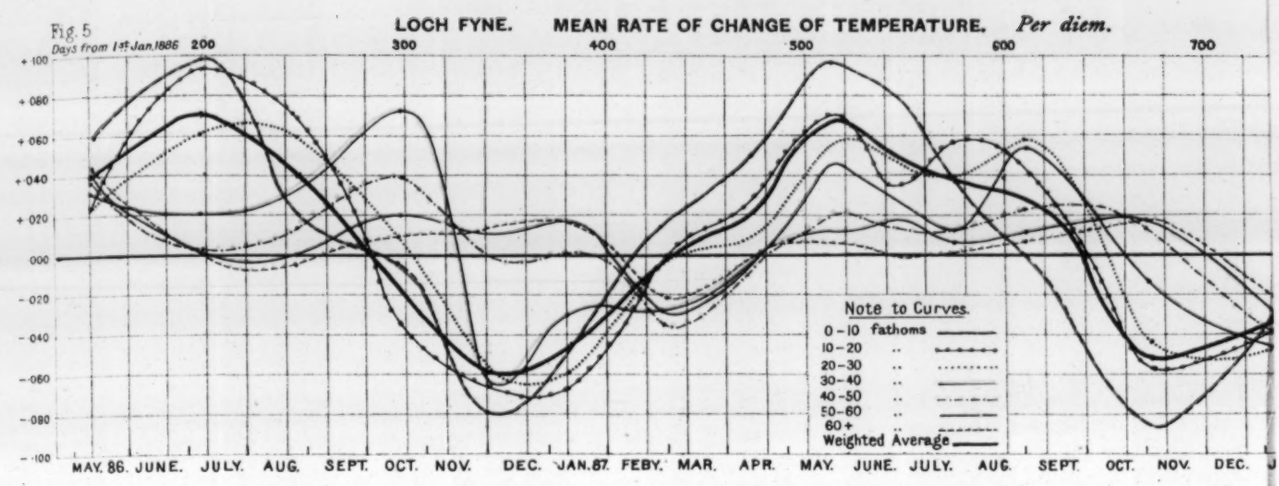


Fig. 6

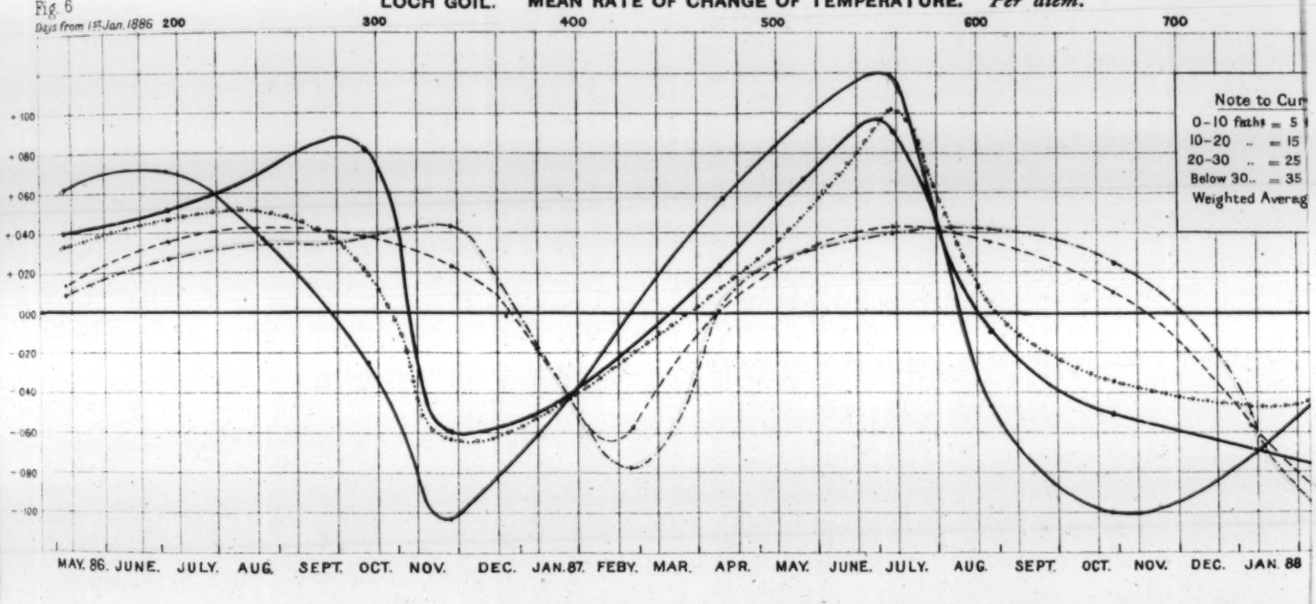
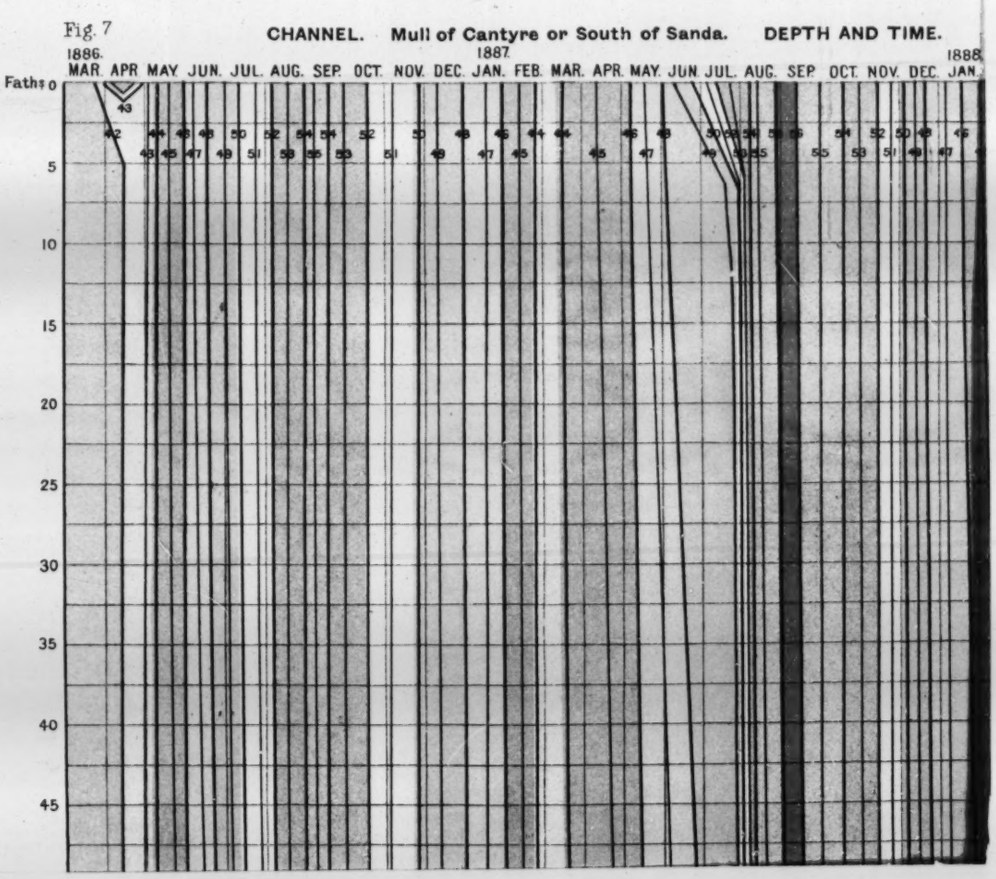


Fig. 7

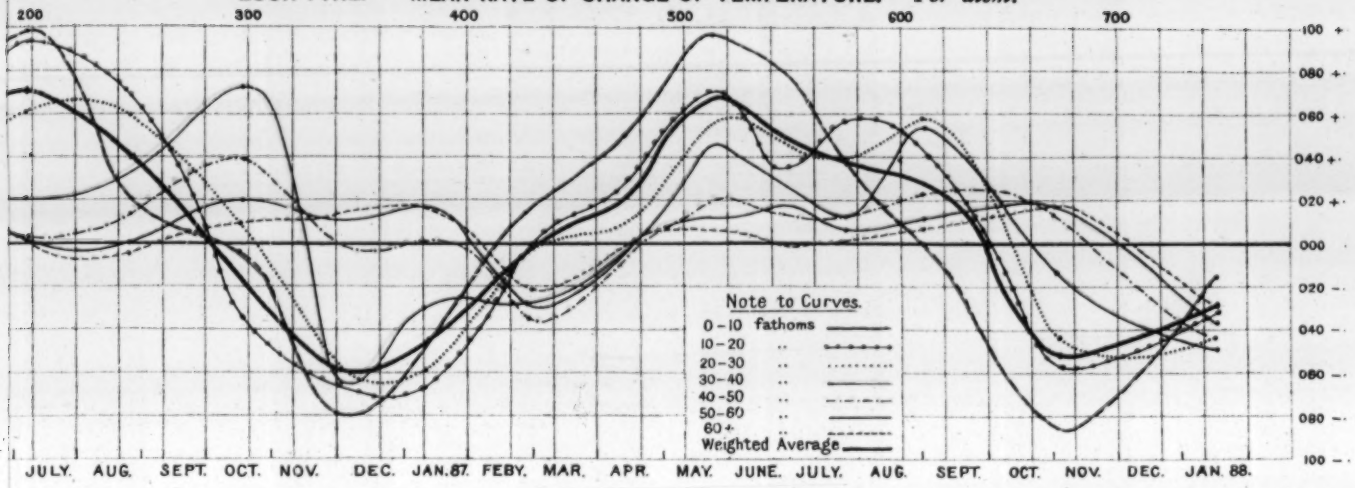


SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° - 54°
50° - 52°
48° - 50°
46° - 48°
44° - 46°
42° - 44°
40° - 42°
BELOW 40°

TEMPERATURE VARIATIONS

LOCH FYNE. MEAN RATE OF CHANGE OF TEMPERATURE. ***Per diem.***



LOCH GOIL. MEAN RATE OF CHANGE OF TEMPERATURE. ***Per diem.***

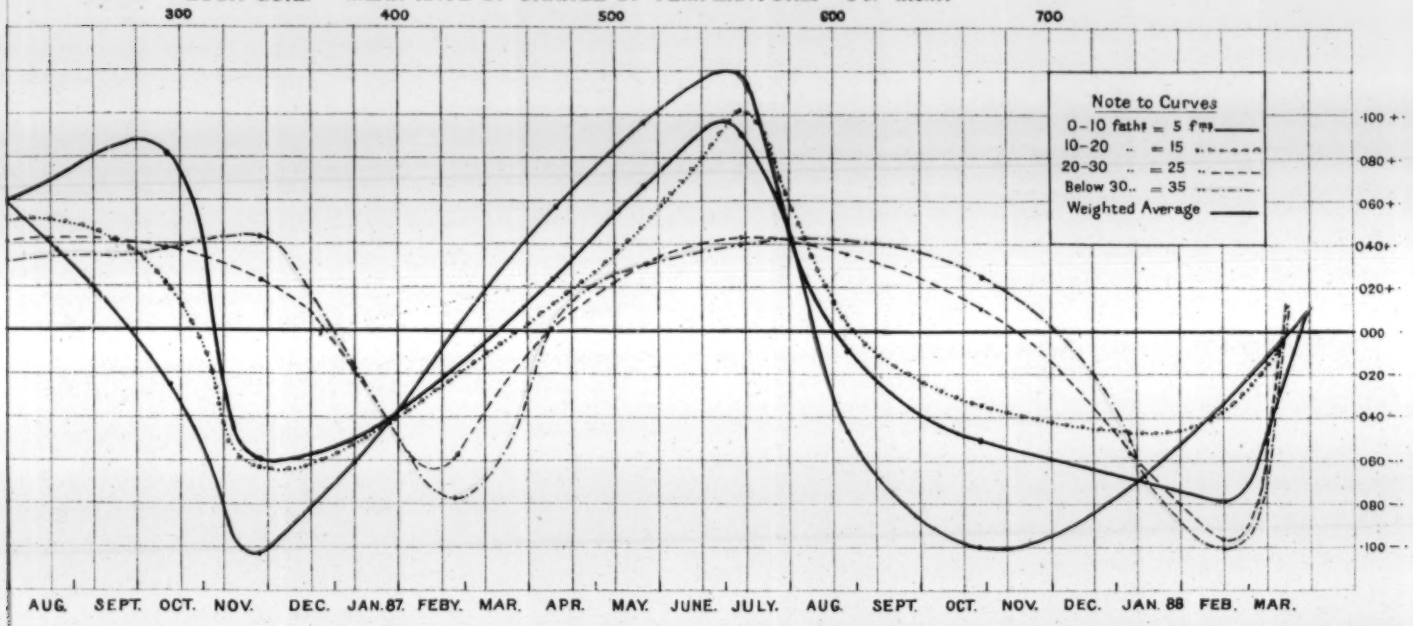
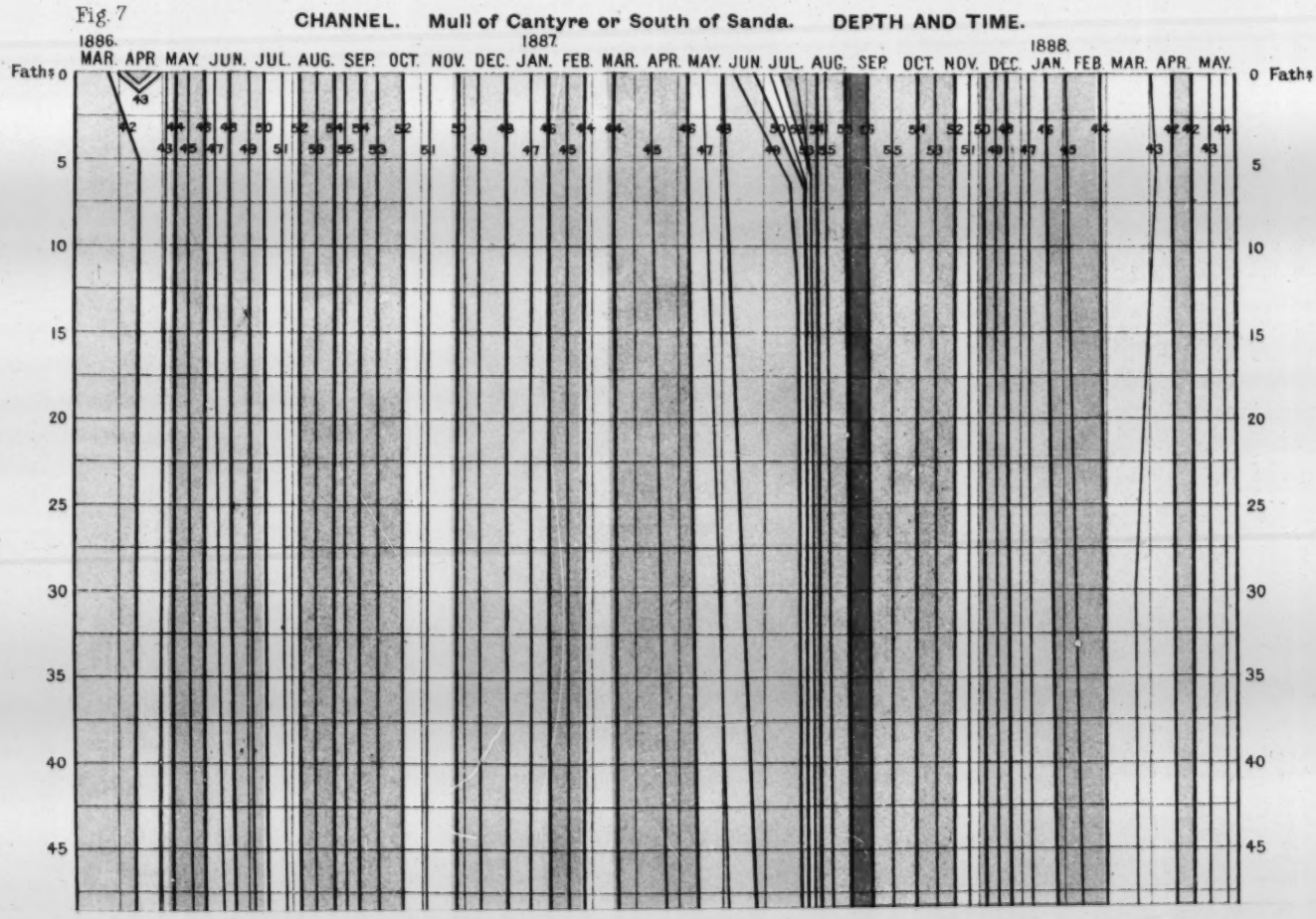


Fig. 7

CHANNEL. Mull of Cantyre or South of Sanda. DEPTH AND TIME.



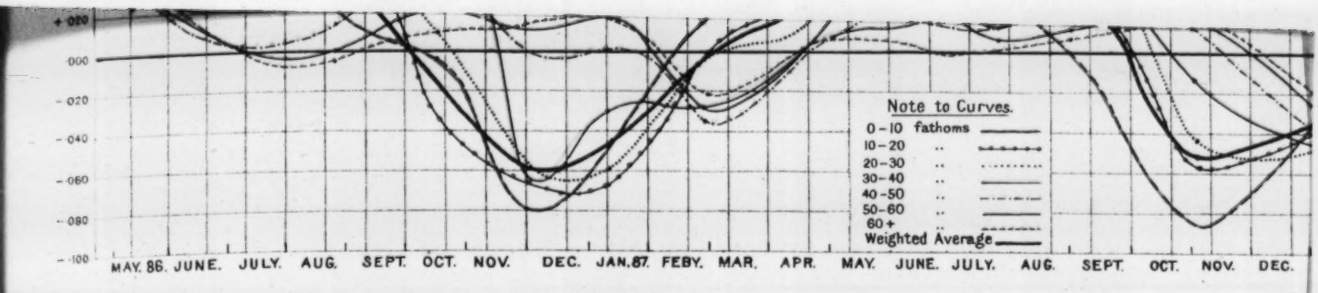


Fig. 6

LOCH GOIL. MEAN RATE OF CHANGE OF TEMPERATURE. *Per diem.*

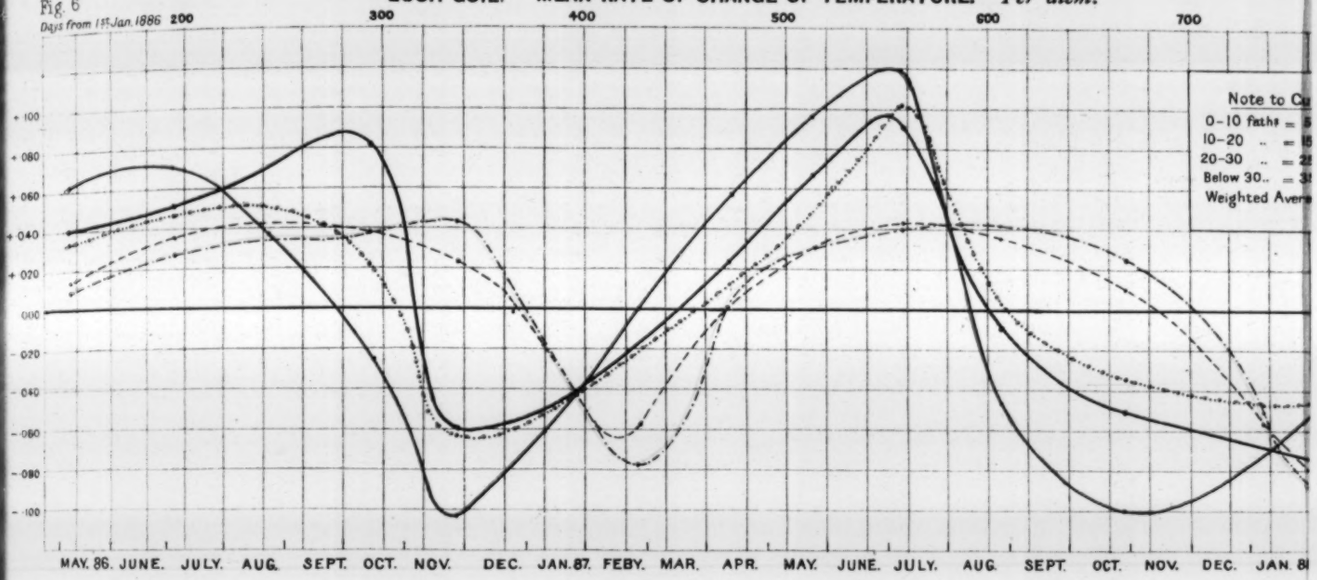
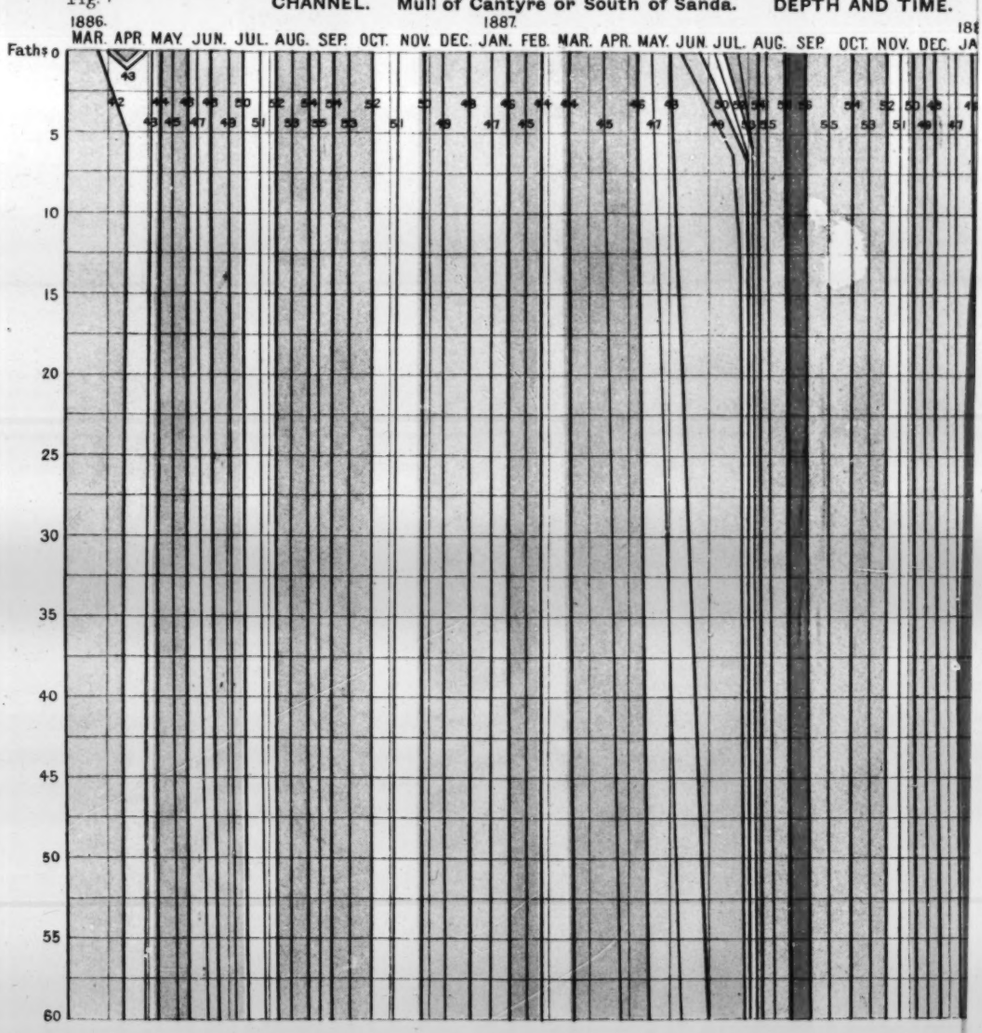


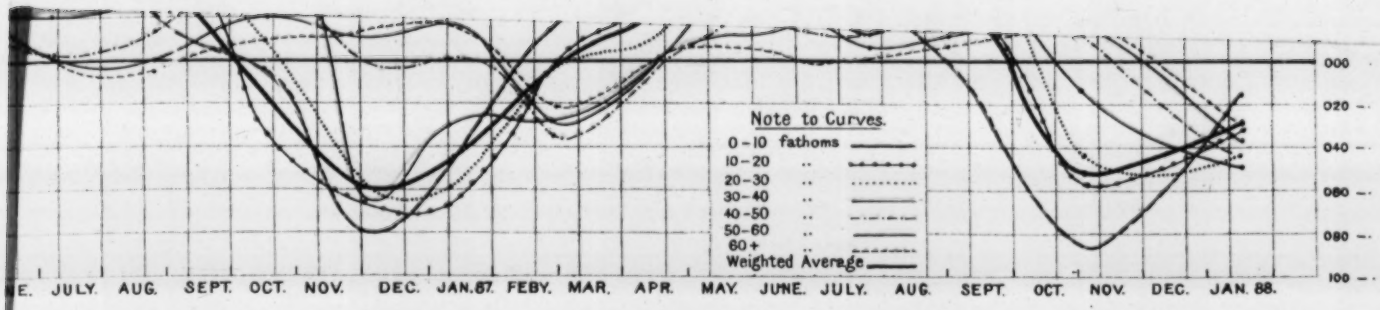
Fig. 7

CHANNEL. Mull of Cantyre or South of Sanda. DEPTH AND TIME.



SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
BELOW 40°



LOCH GOIL. MEAN RATE OF CHANGE OF TEMPERATURE. *Per diem.*

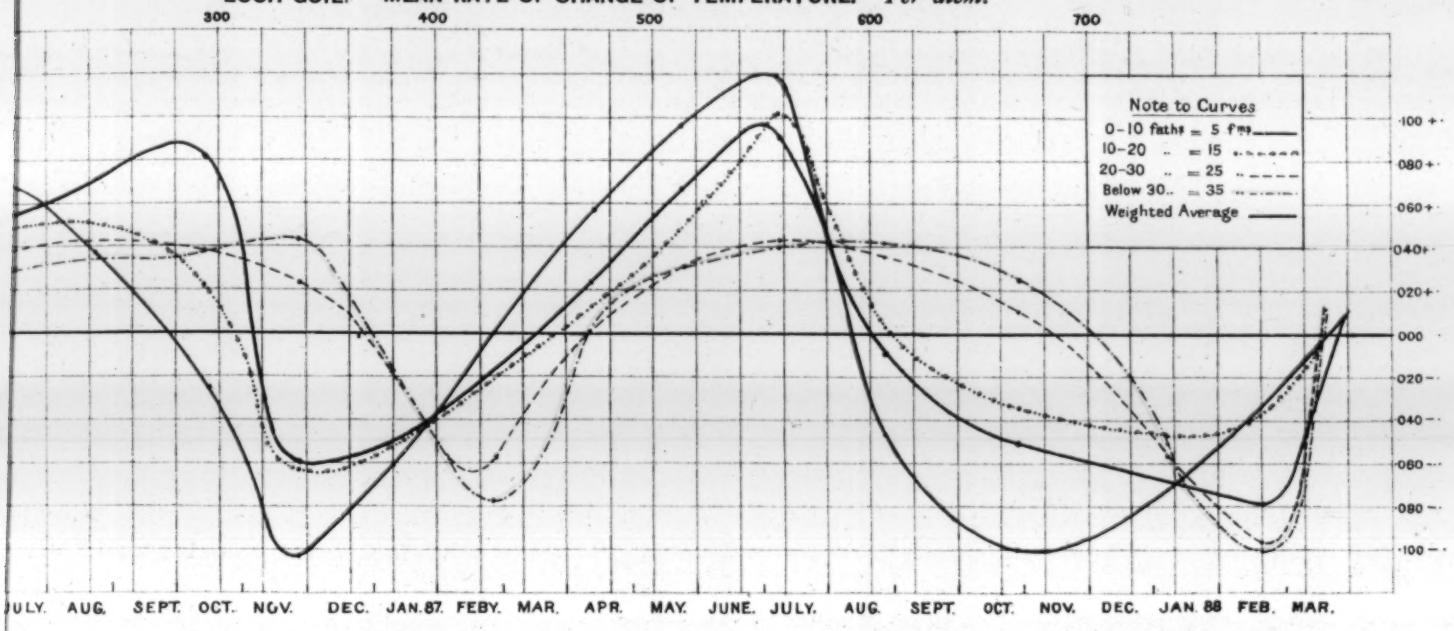
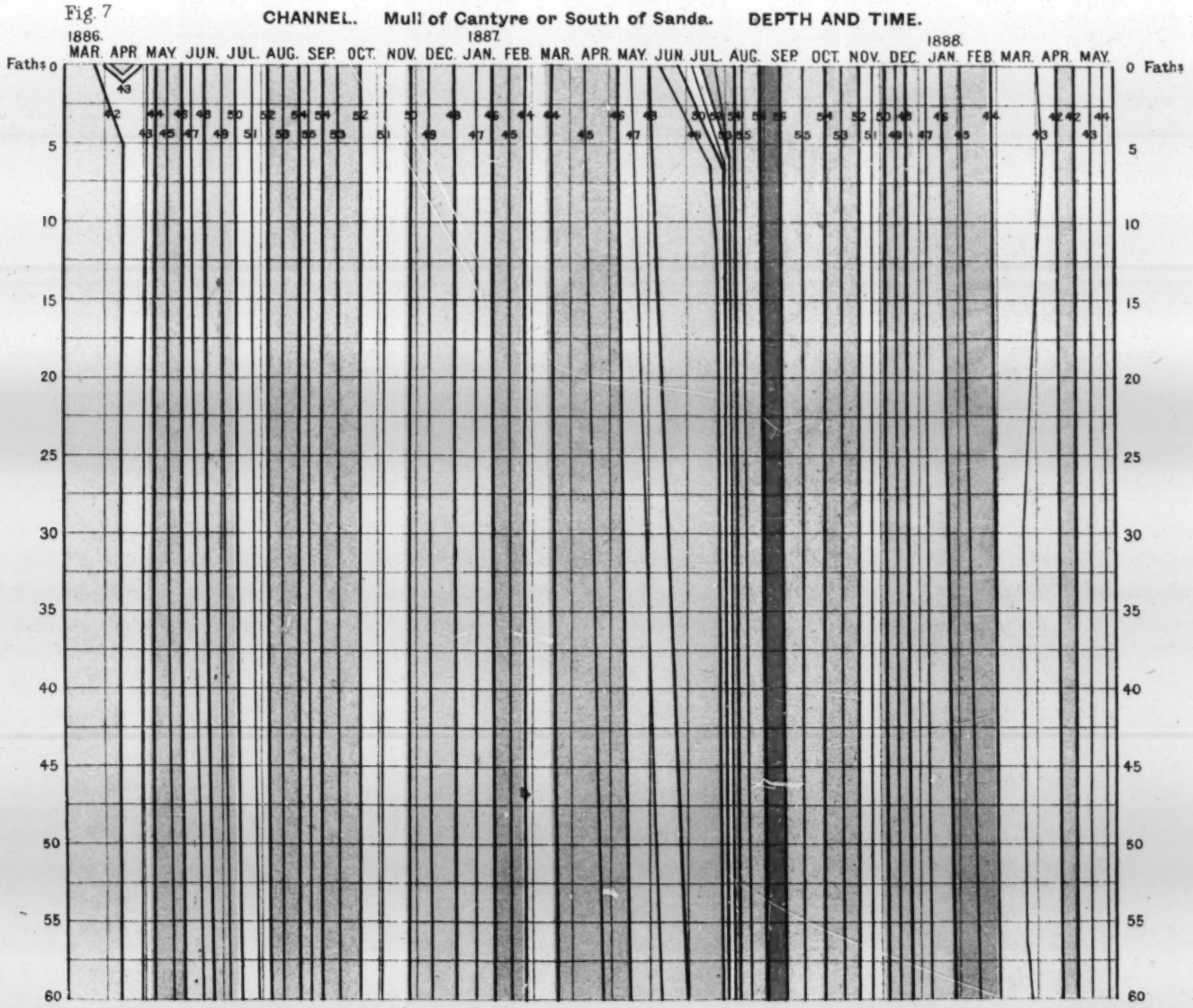


Fig. 7

CHANNEL.. Mull of Cantyre or South of Sanda. DEPTH AND TIME.



Bartholomew, Edin.r

TEMPERATURE VARIATIONS

Fig. 8

STRACHUR. Loch Fyne. DEPTH AND TIME.

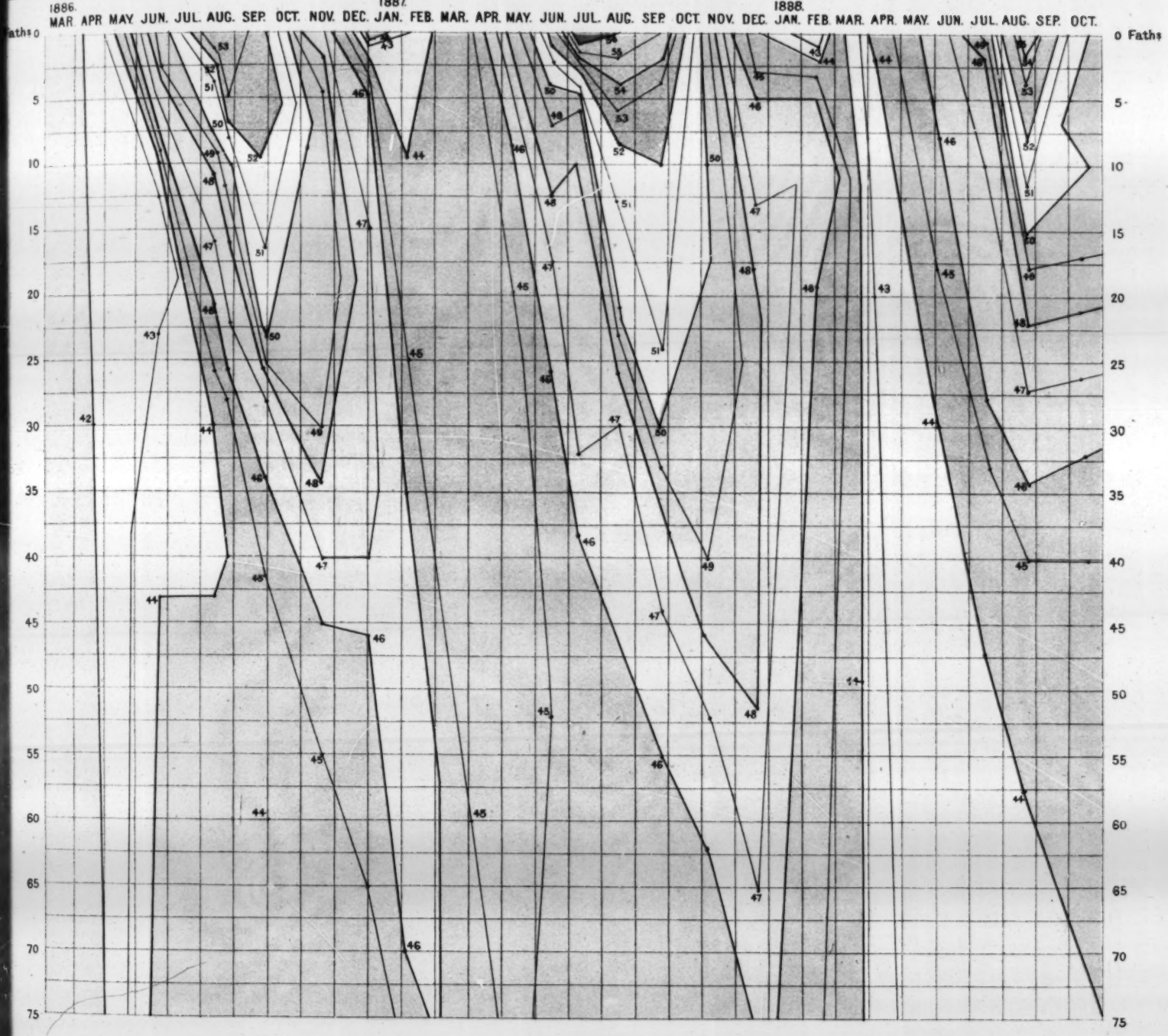
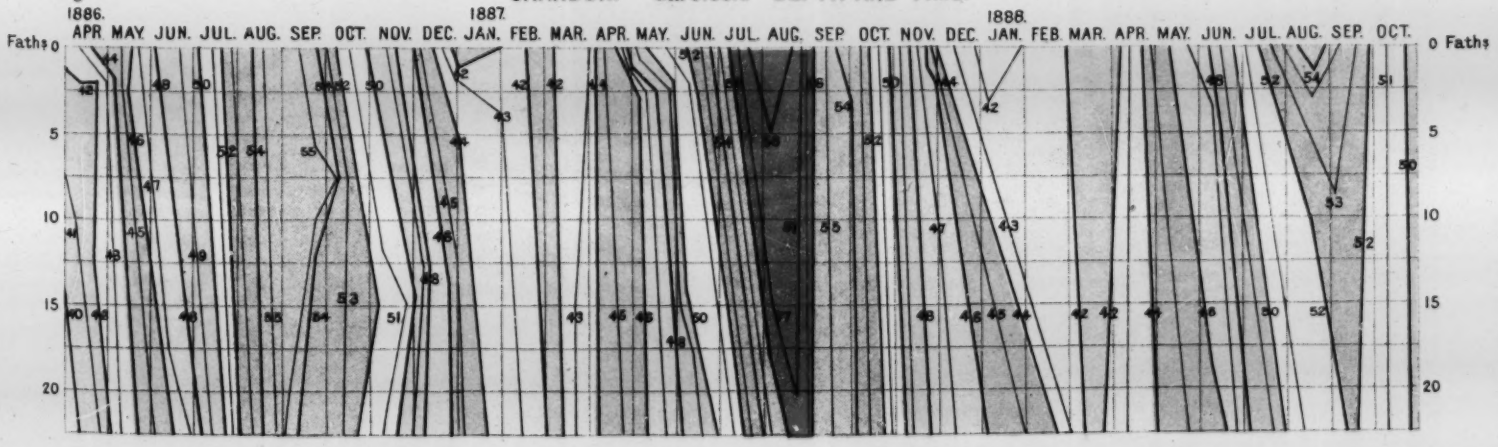


Fig. 9

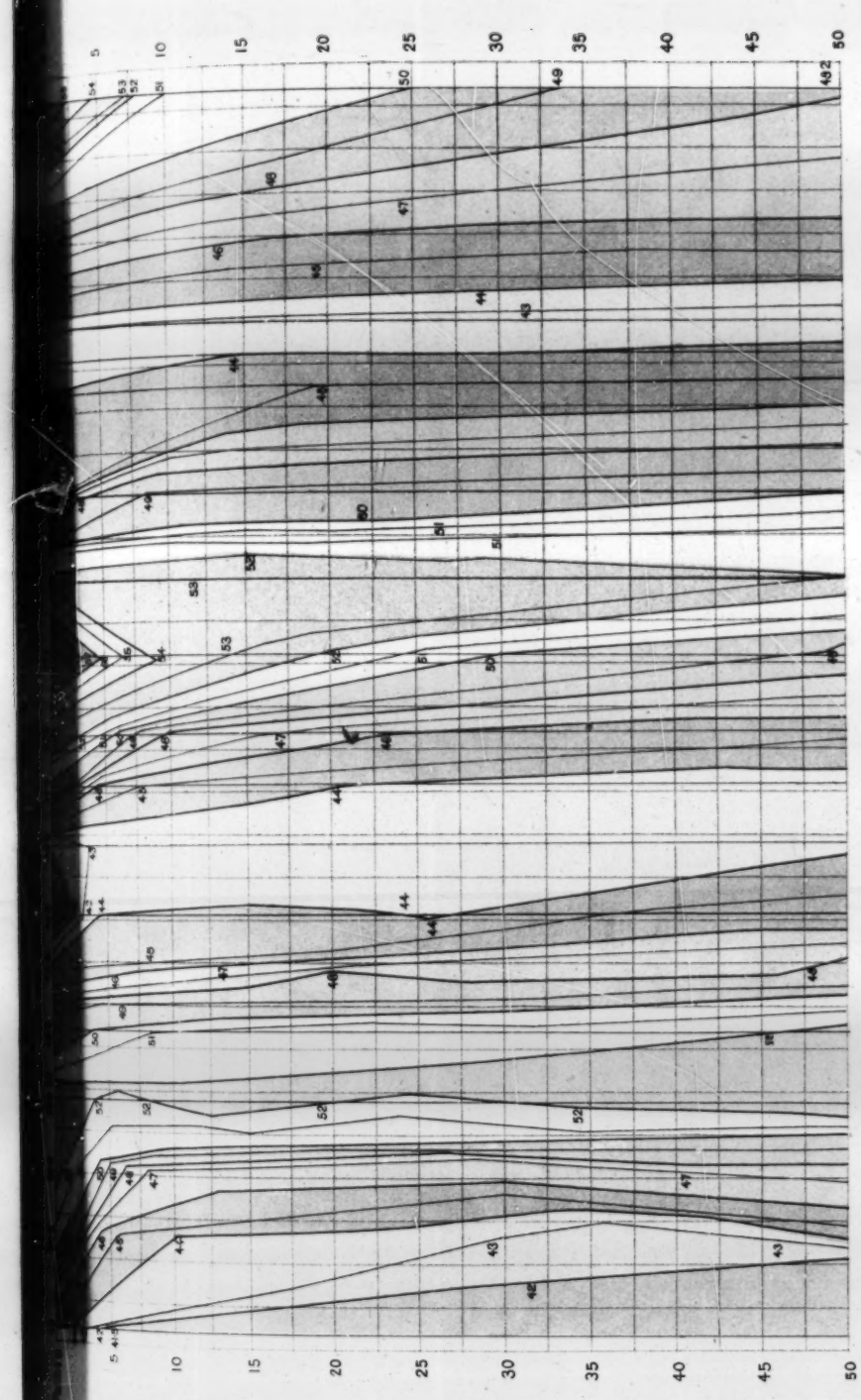
SHANDON. Gareloch. DEPTH AND TIME.



OF COLOURING
TEMPERATURE

56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
Below 40°

TEMPERATURE VARIATIONS



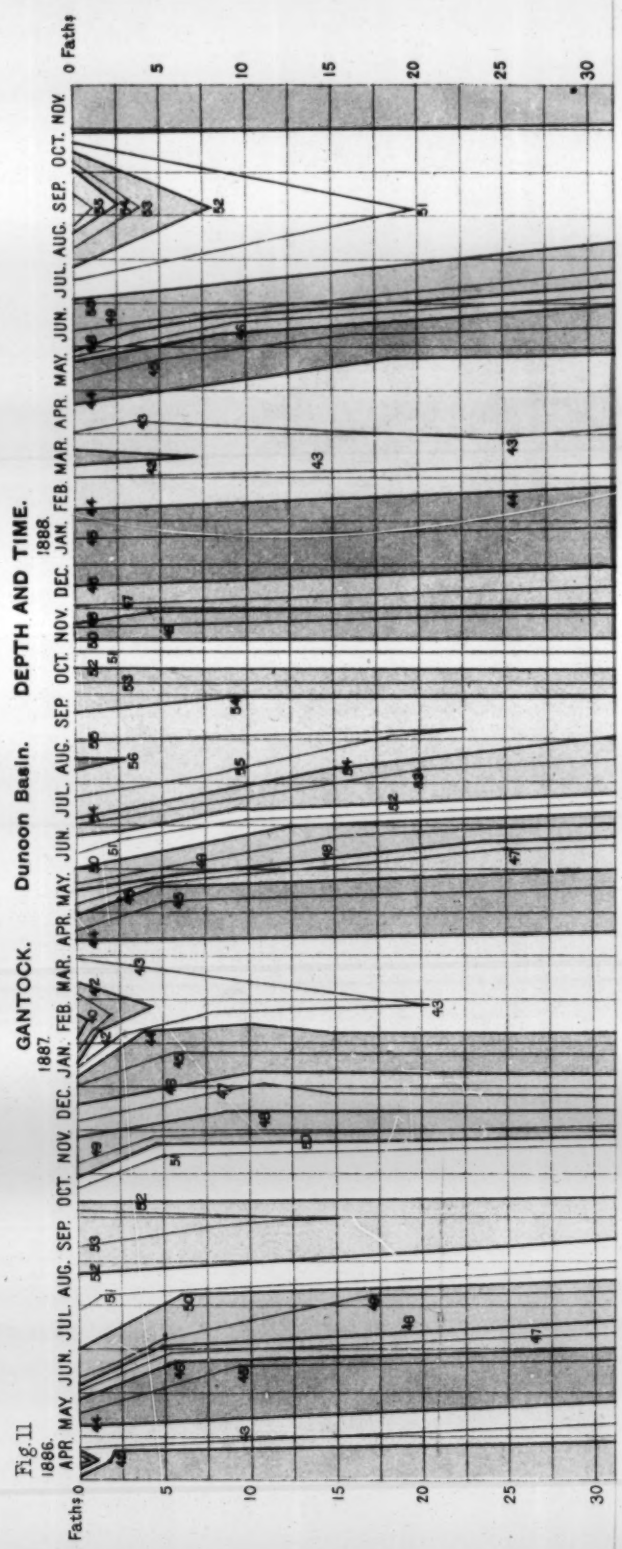
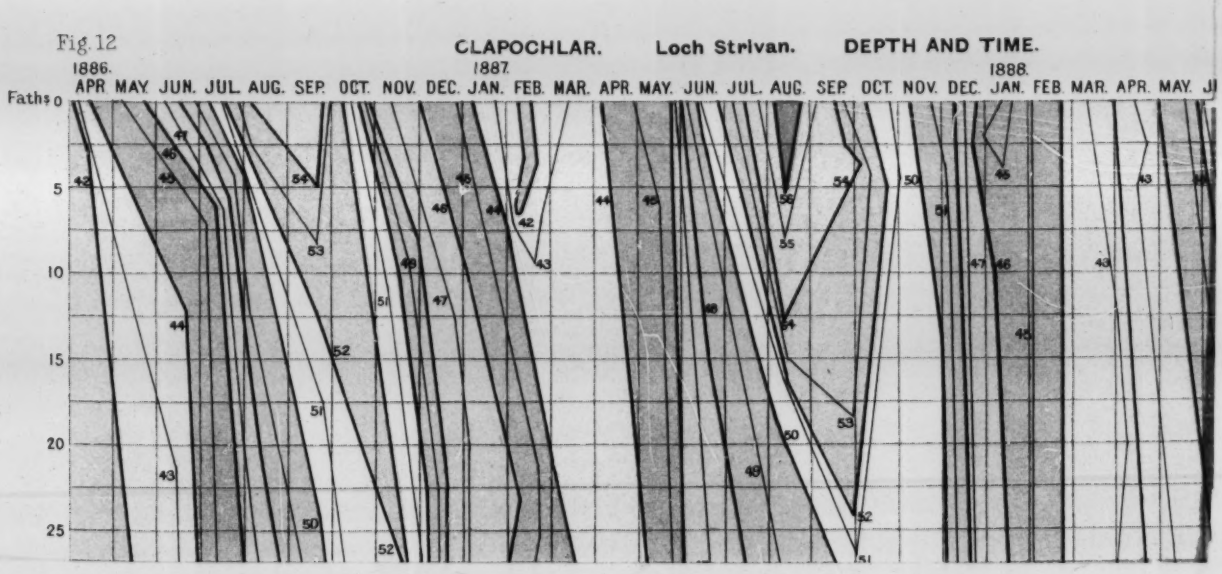


Fig. 11

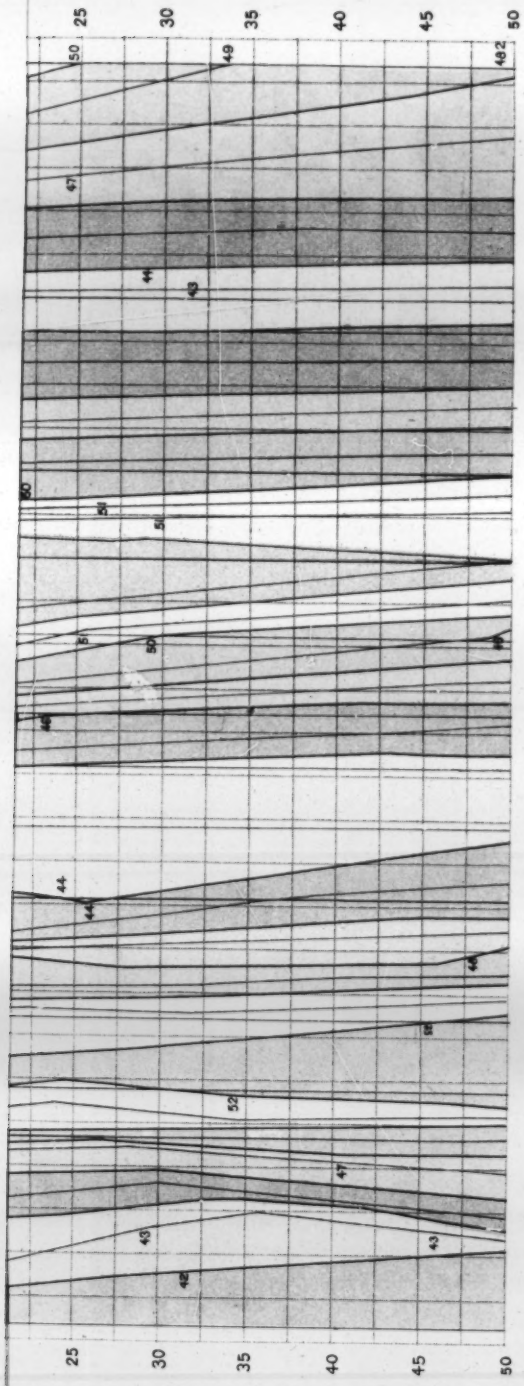
Fig. 12



SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
BELOW 40°

TEMPERATURE VARIATIONS



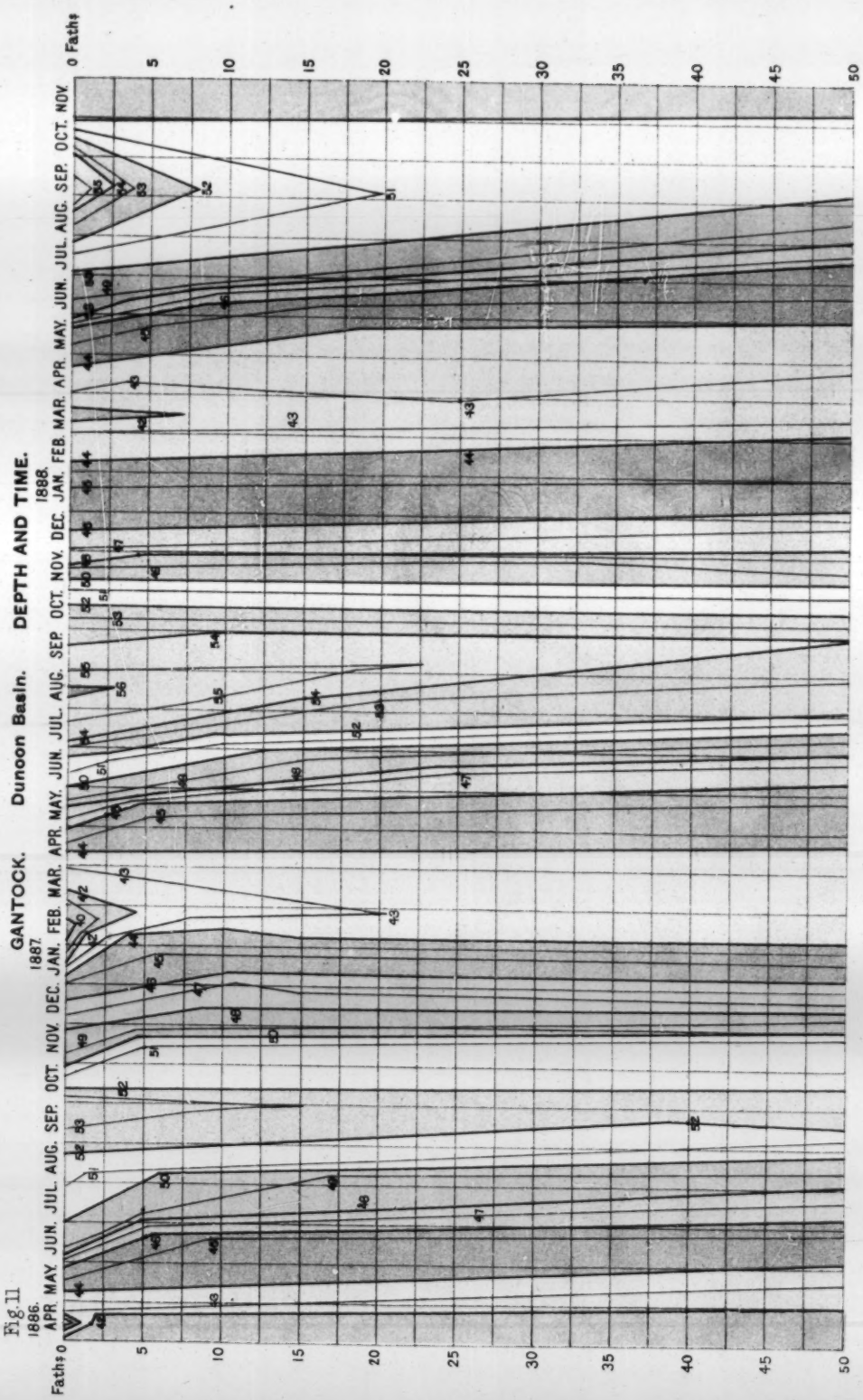
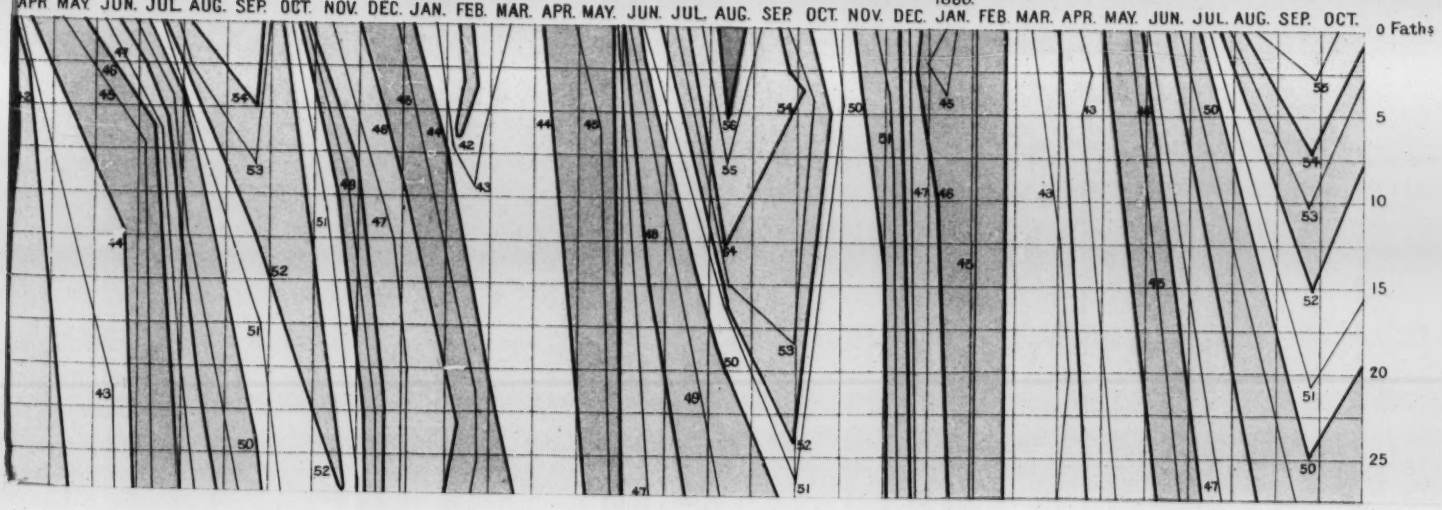
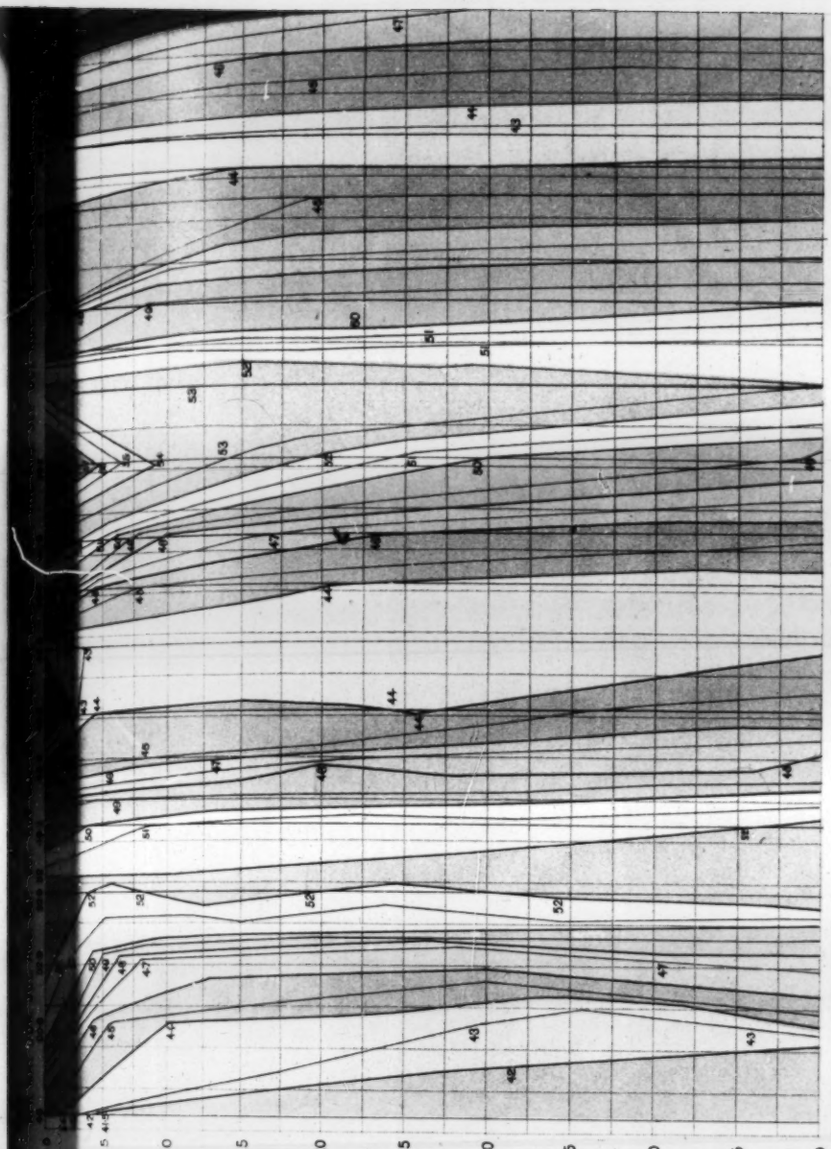


Fig.11

Fig.12





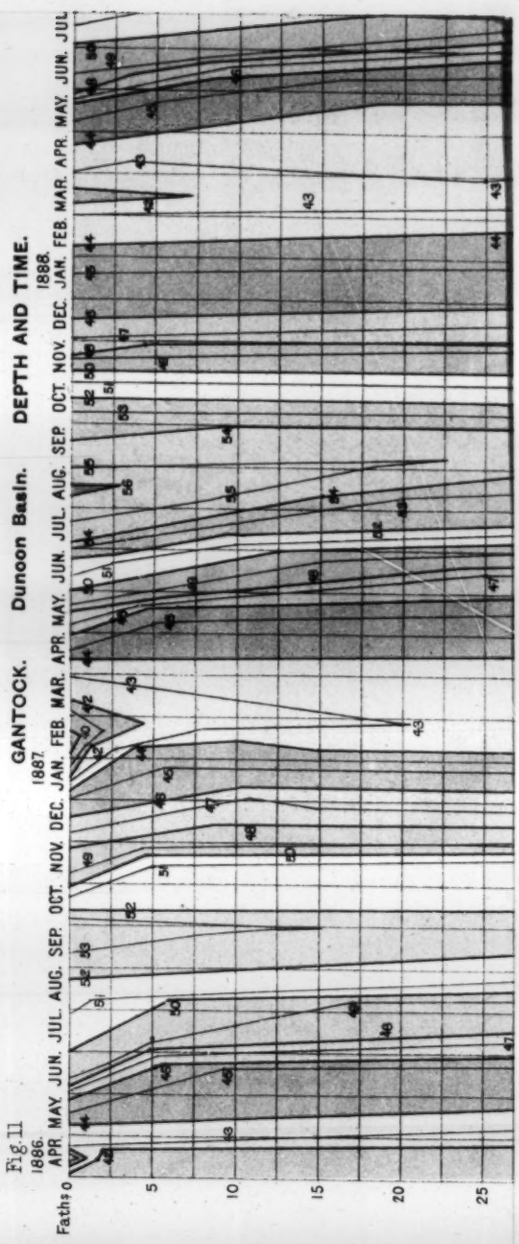
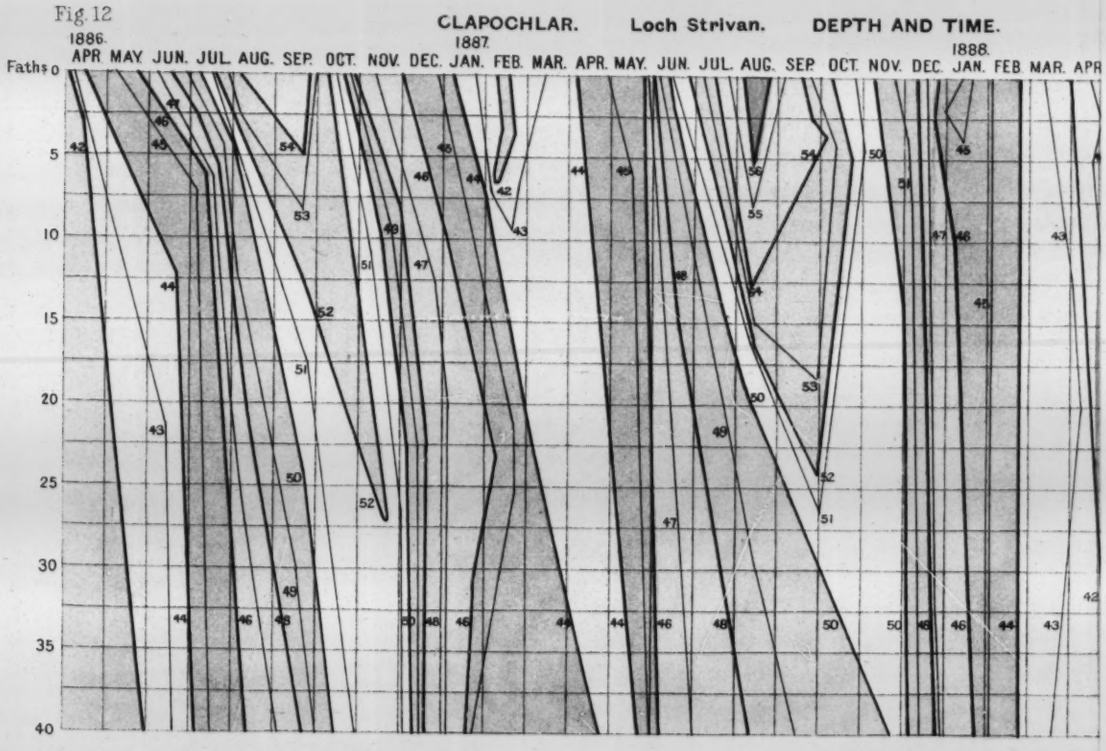


Fig. 11

Fig. 12



SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
BELOW 40°

Fig.11

GANTOCK. Dunoon Basin. DEPTH AND TIME.

1886. 1887. 1888.

APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL.

Faths 0 5 10 15 20 25 30 35 40 45 50

Fig.12

CLAPOCHLAR. Loch Strivan. DEPTH AND TIME.

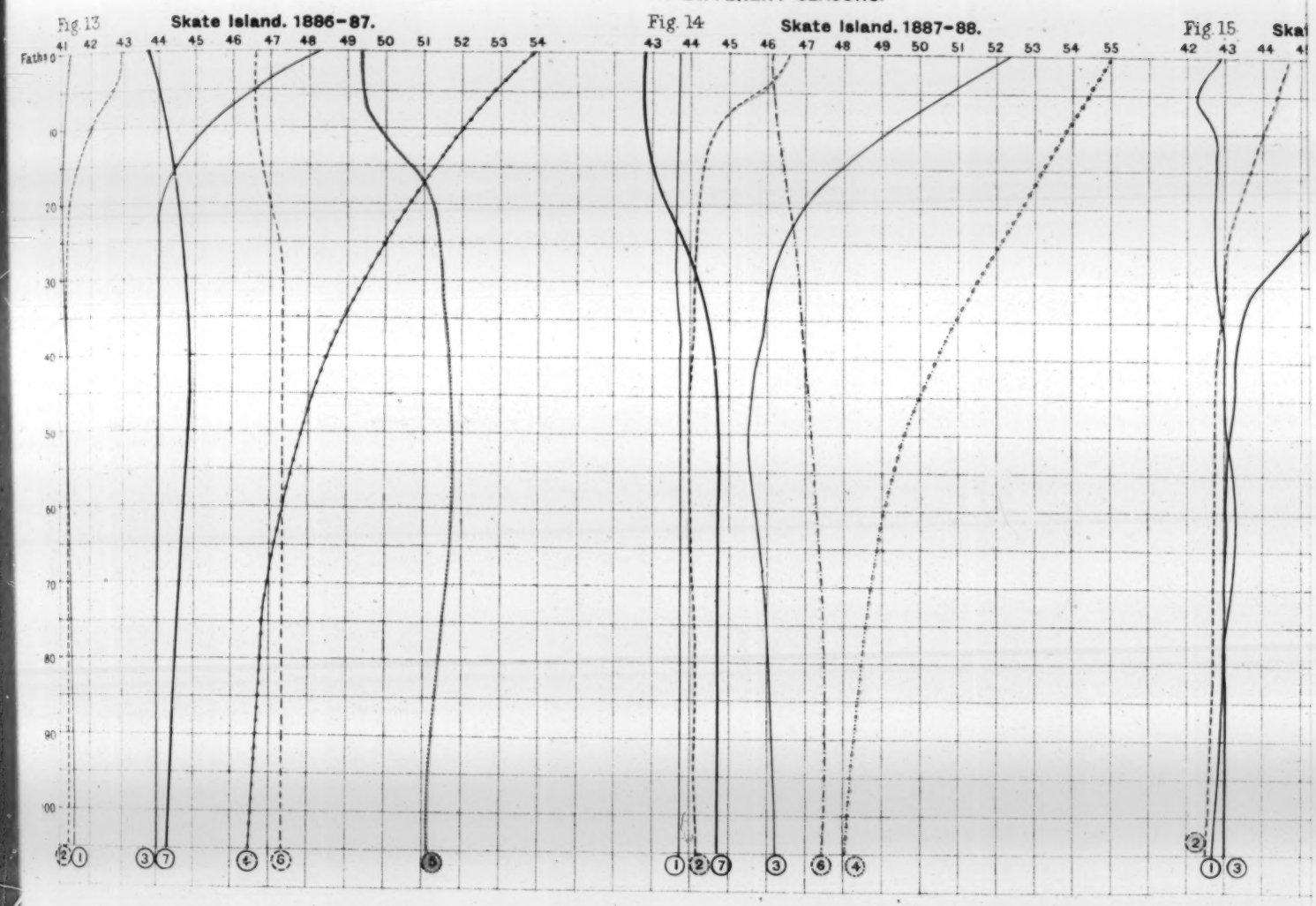
1886. 1887. 1888.

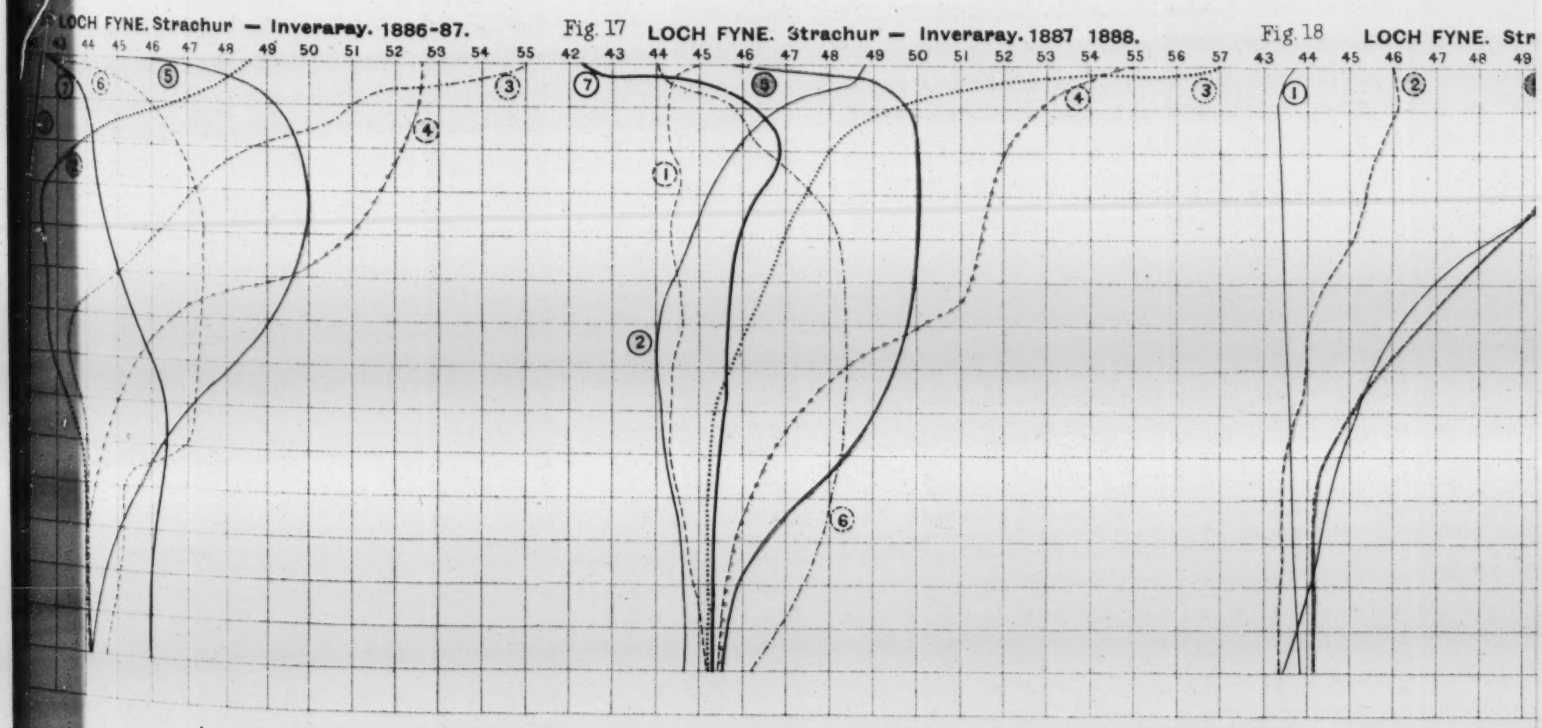
APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT.

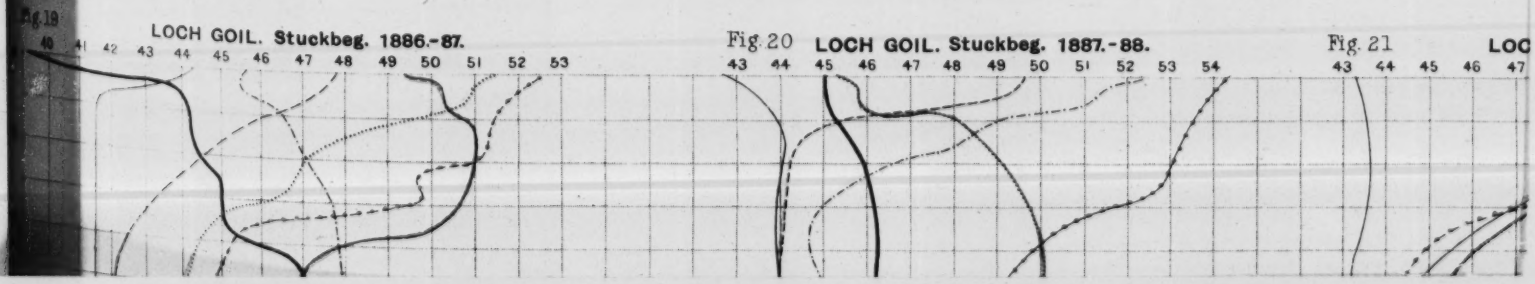
0 Faths 5 10 15 20 25 30 35 40

Bartholomew, Edin.

VERTICAL TEMPERATURE CURVES
AT DIFFERENT SEASONS.







VERTICAL TEMPERATURE CURVES

AT DIFFERENT SEASONS.

Fig. 14 **Skate Island. 1887–88.**

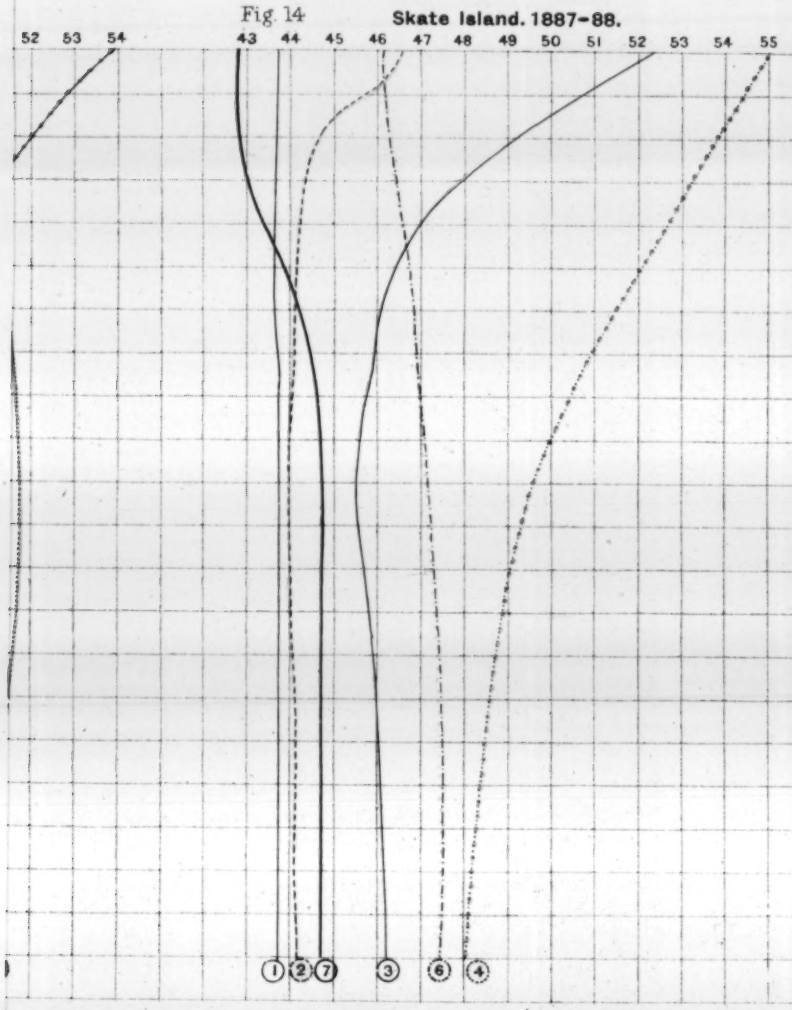


Fig. 15 **Skate Island. 1888.**

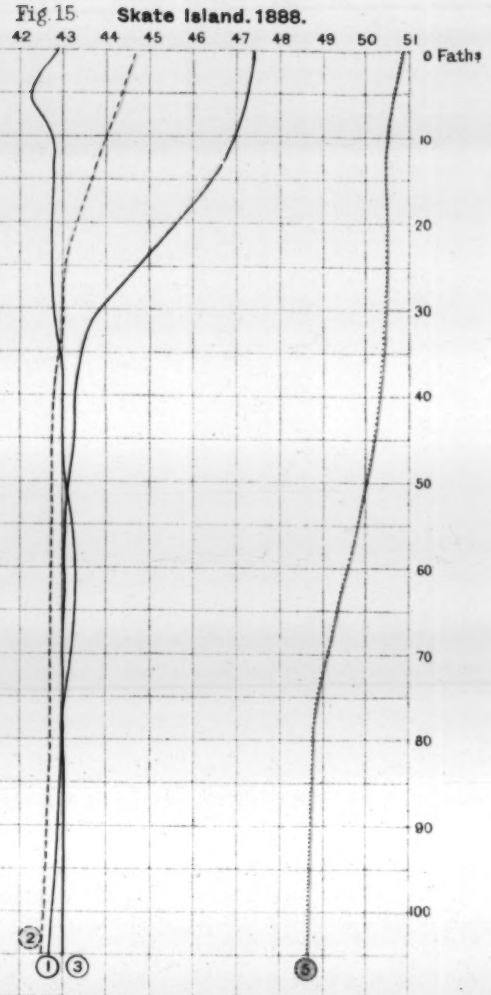


Fig. 17 **LOCH FYNE. Strachur — Inveraray. 1887 1888.**

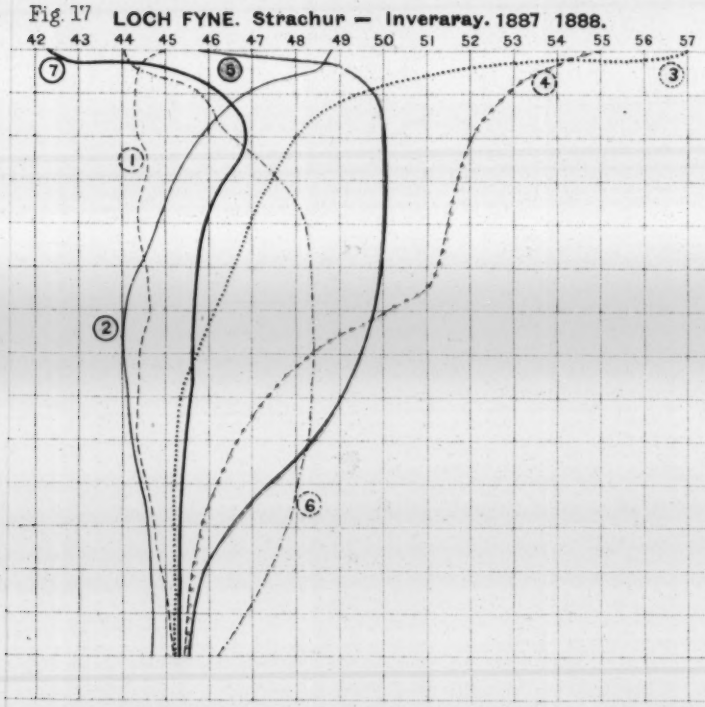


Fig. 18 **LOCH FYNE. Strachur — Inveraray. 1888.**

Fig. 20 **LOCH GOIL. Stuckbeg. 1887.-88.**

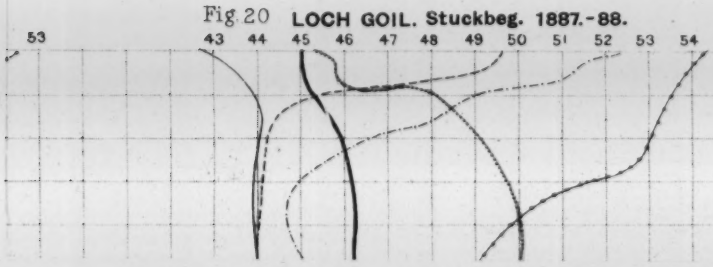
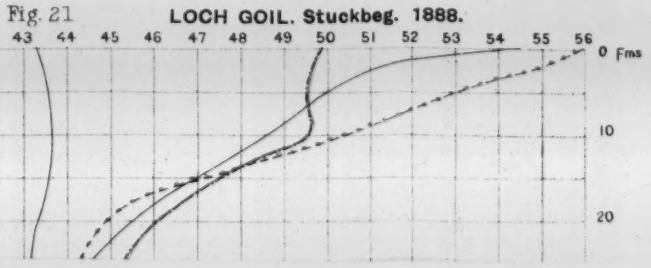


Fig. 21 **LOCH GOIL. Stuckbeg. 1888.**



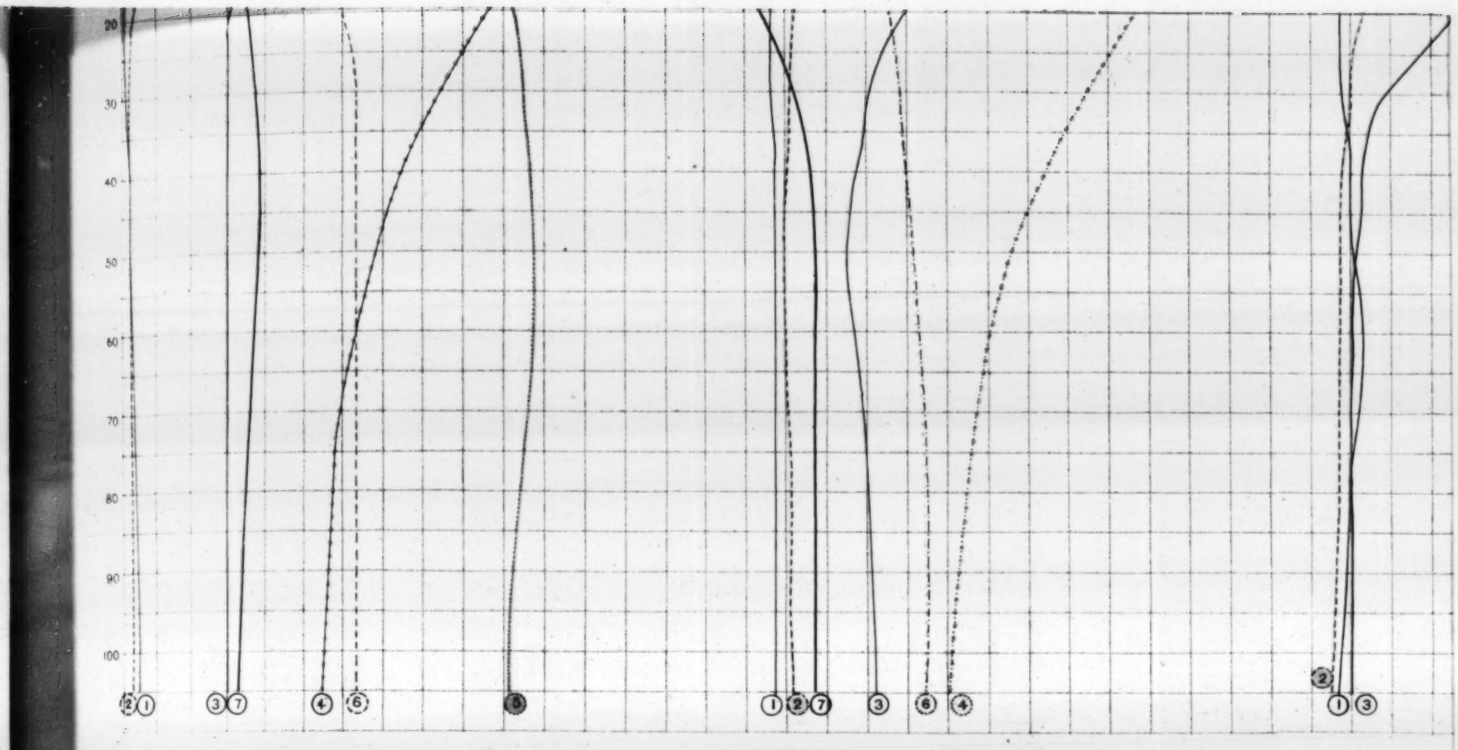


Fig. 16 LOCH FYNE. Strachur — Inveraray. 1886-87.

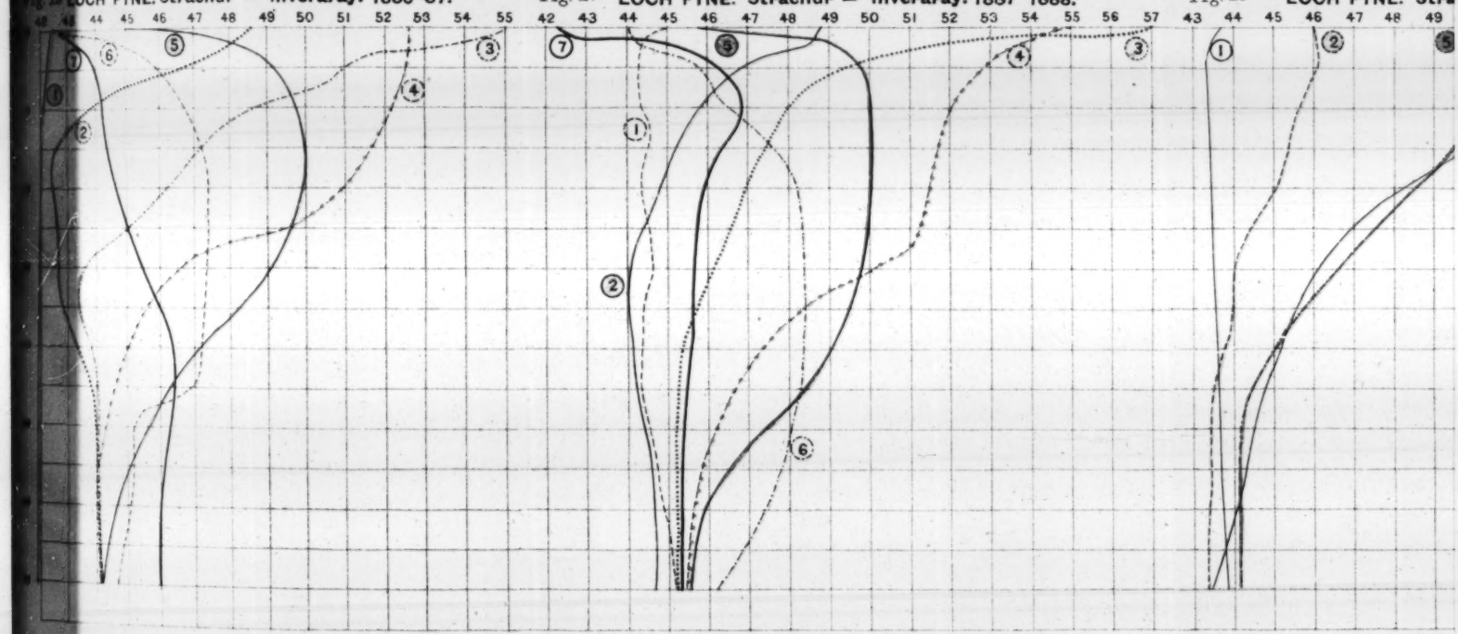


Fig. 17 LOCH FYNE. Strachur — Inveraray. 1887 1888.

Fig. 18 LOCH FYNE. Stra

Fig. 19 LOCH GOIL. Stuckbeg. 1886.-87.

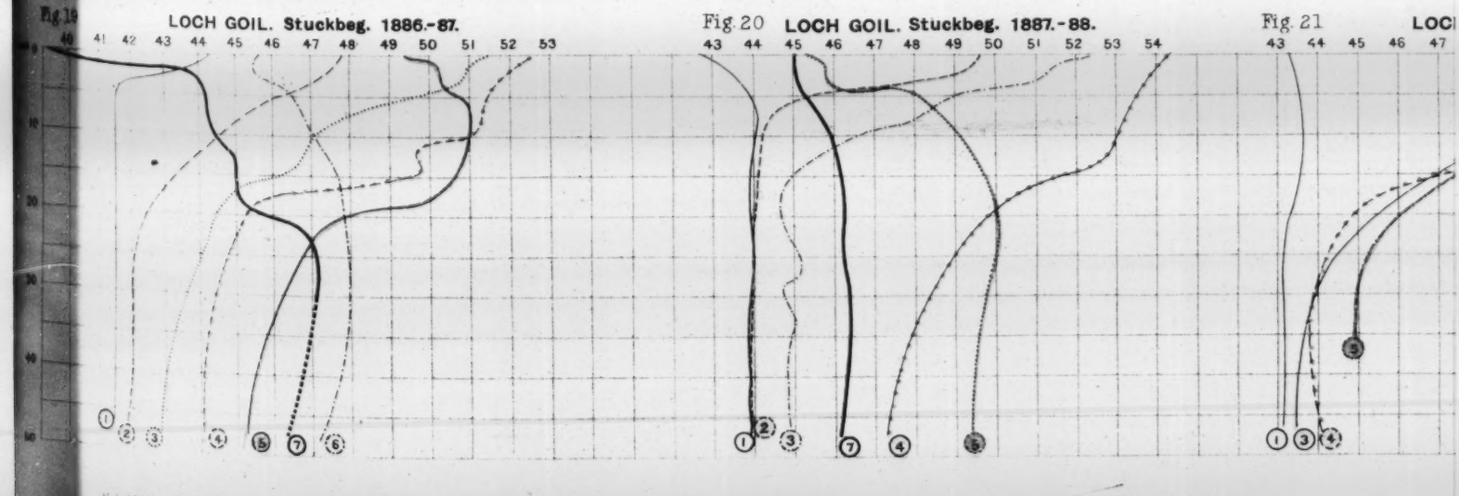
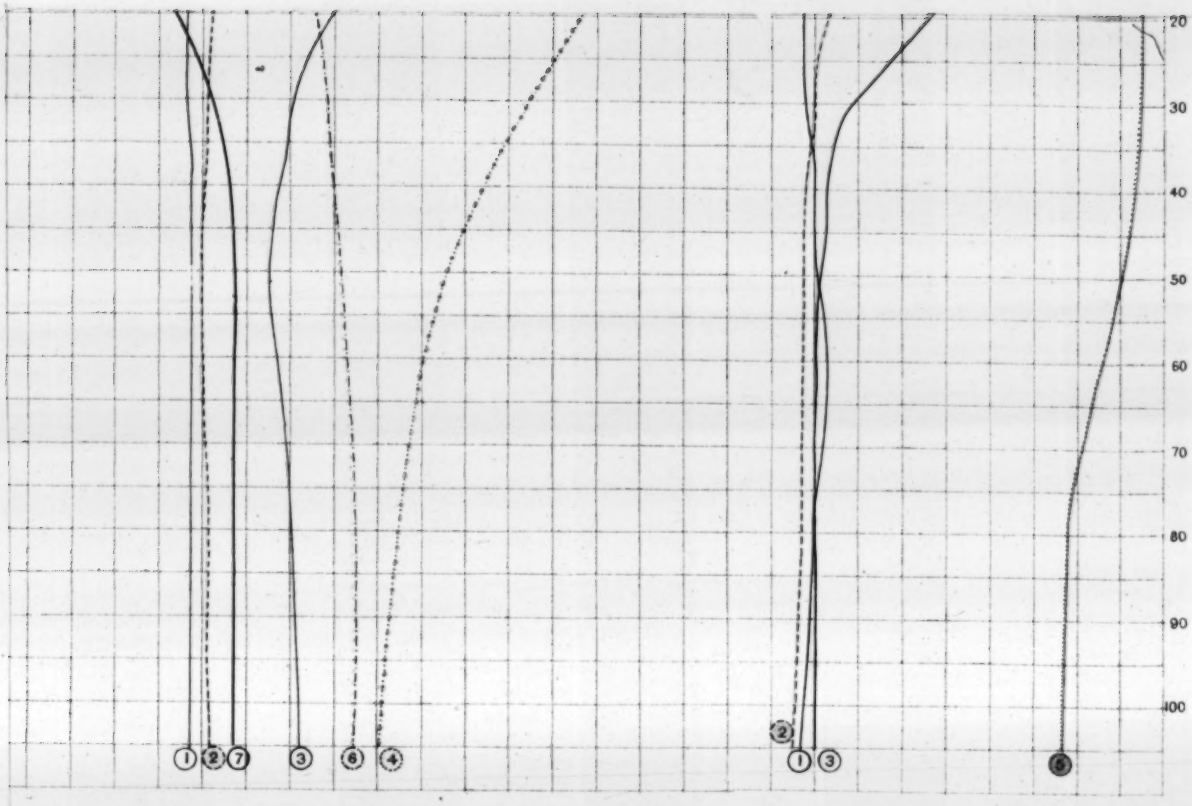


Fig. 20 LOCH GOIL. Stuckbeg. 1887.-88.

Fig. 21 LOCH



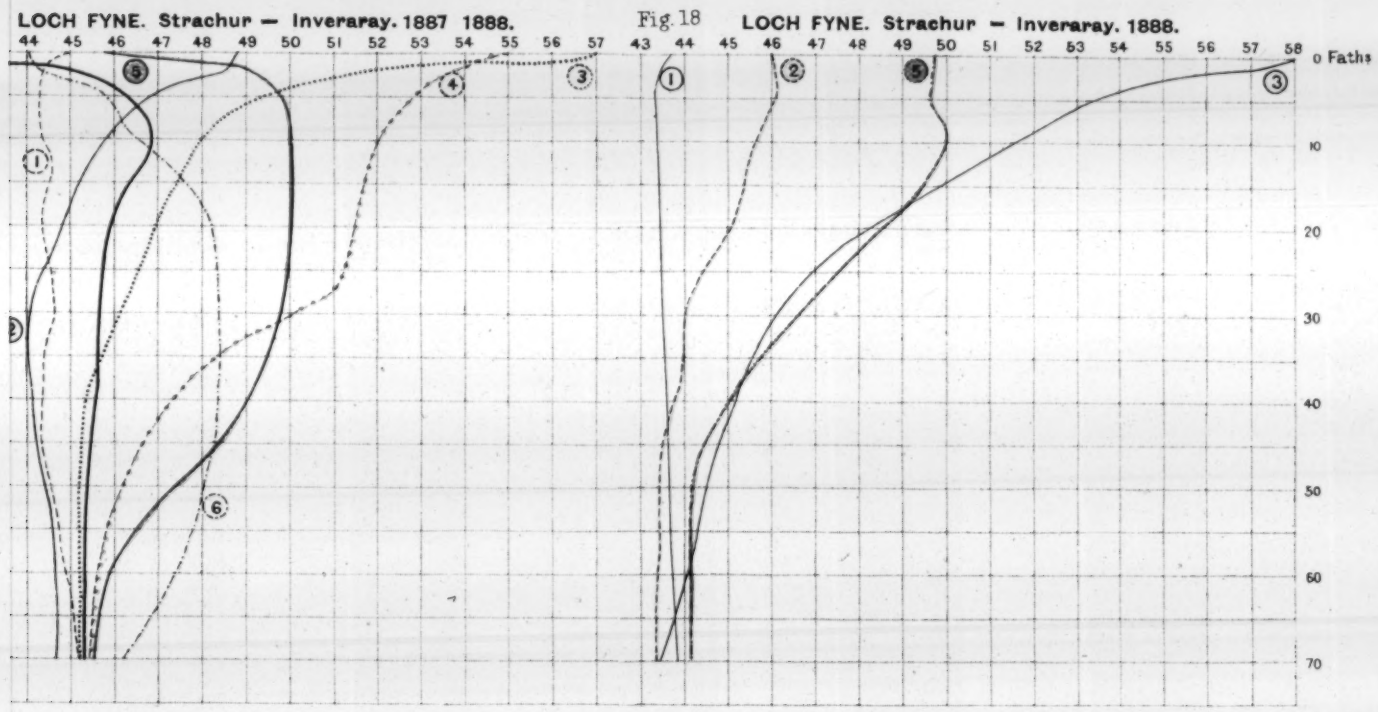
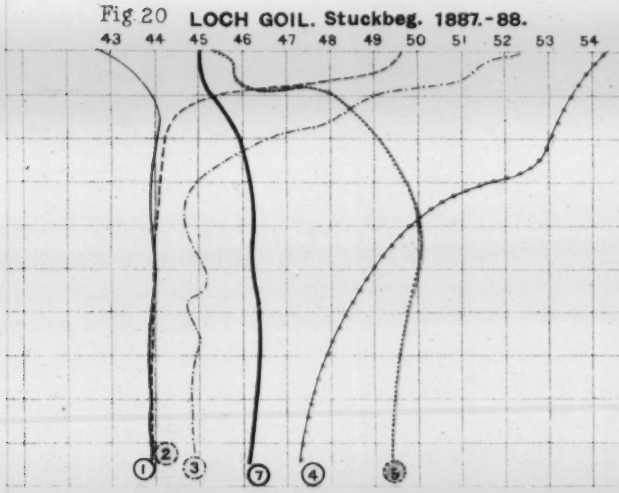
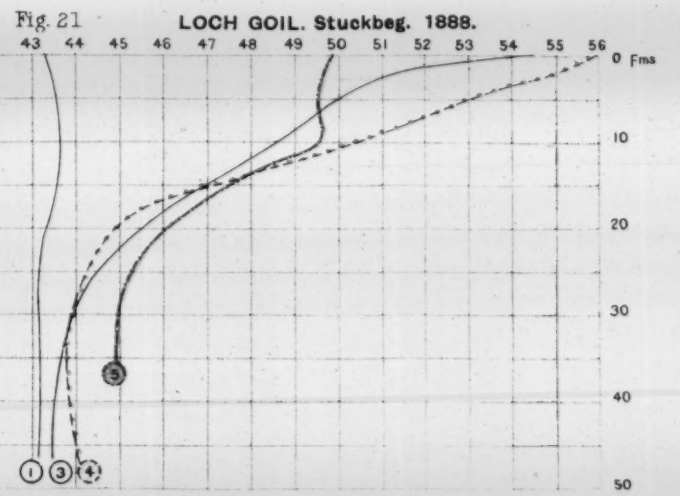


Fig. 18

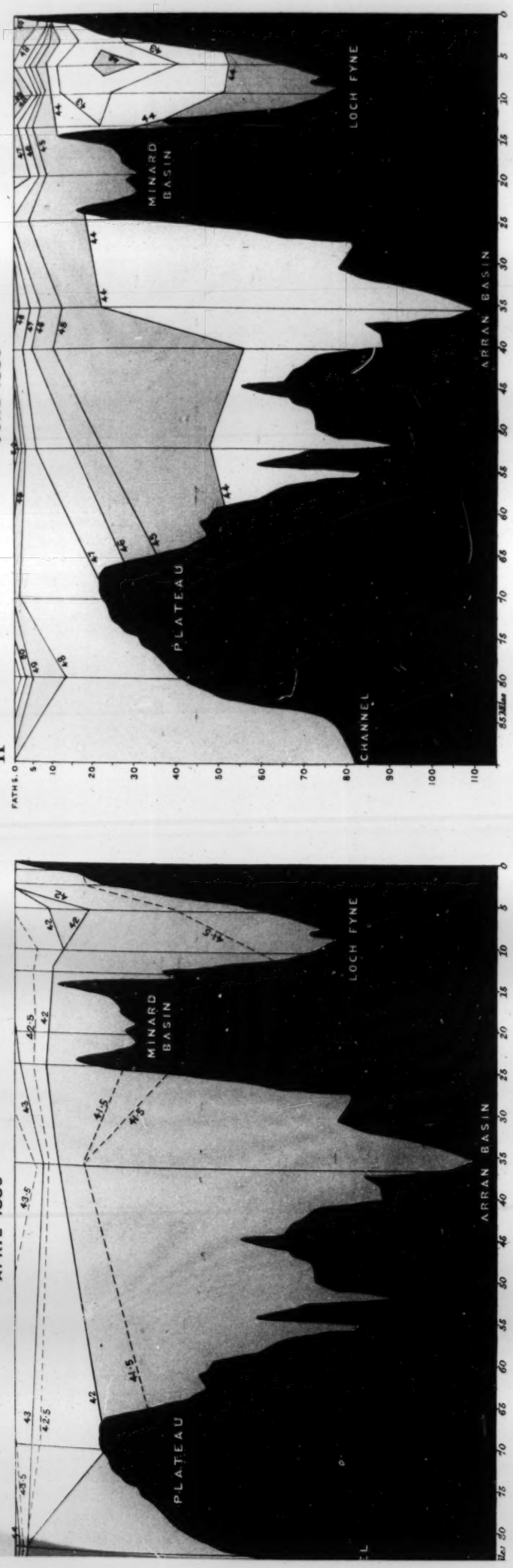




Bartholomew, Edinr

TEMPERATURE SECTIONS OF CLYDE SEA AREA

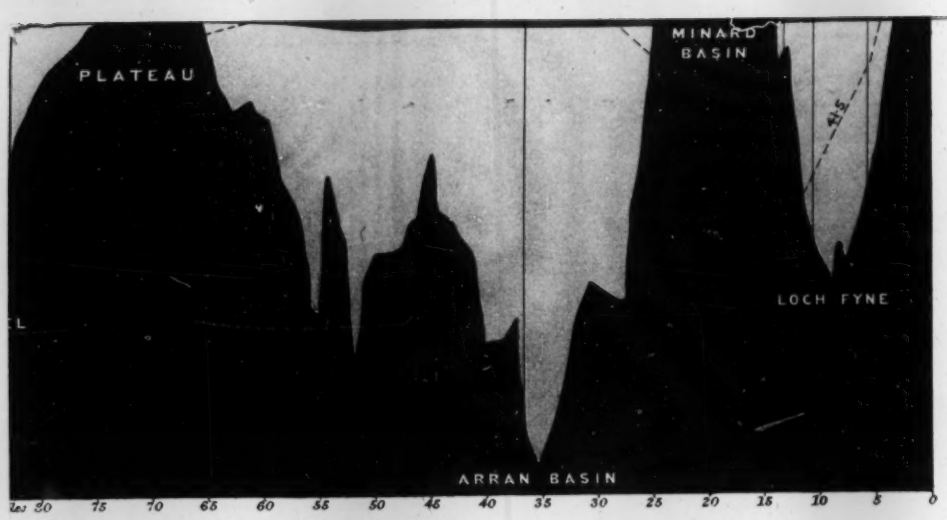
FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE

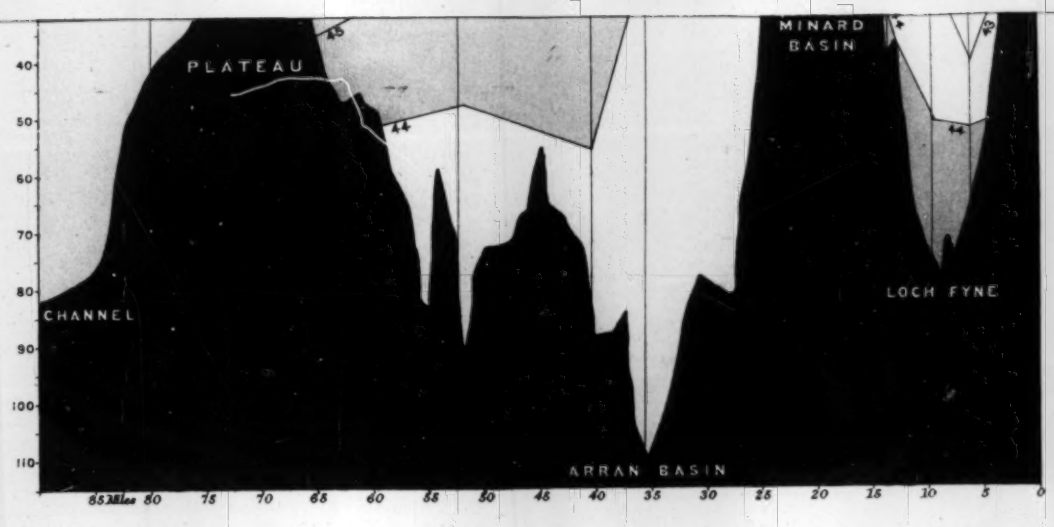


III

TEMPERATURE SECTIONS OF CLYDE SEA AREA

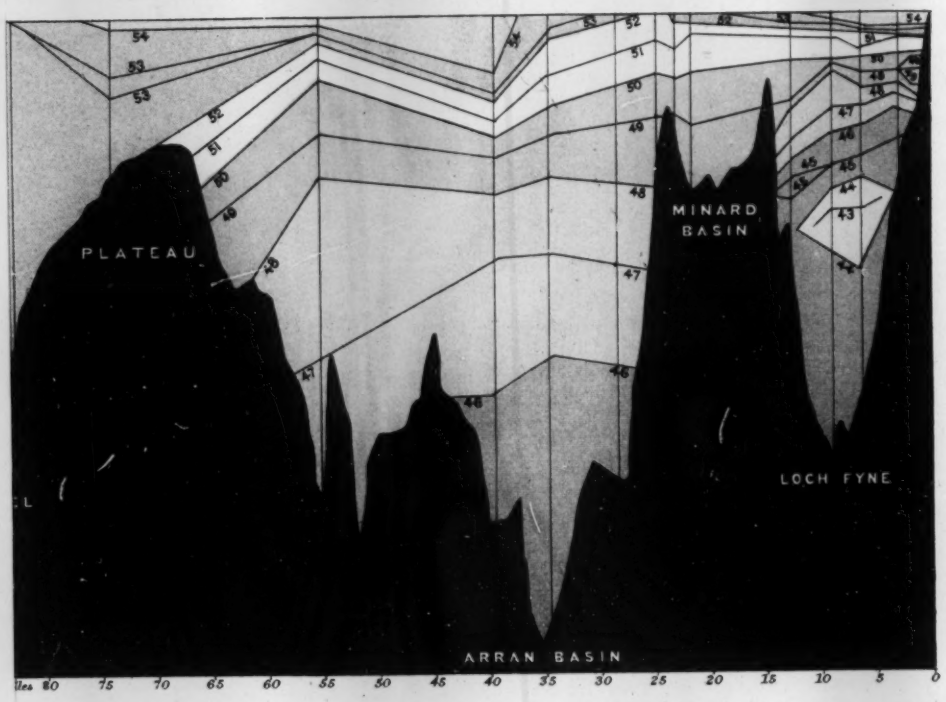
FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE





IV

AUGUST 1886



SEPTEMBER 1886

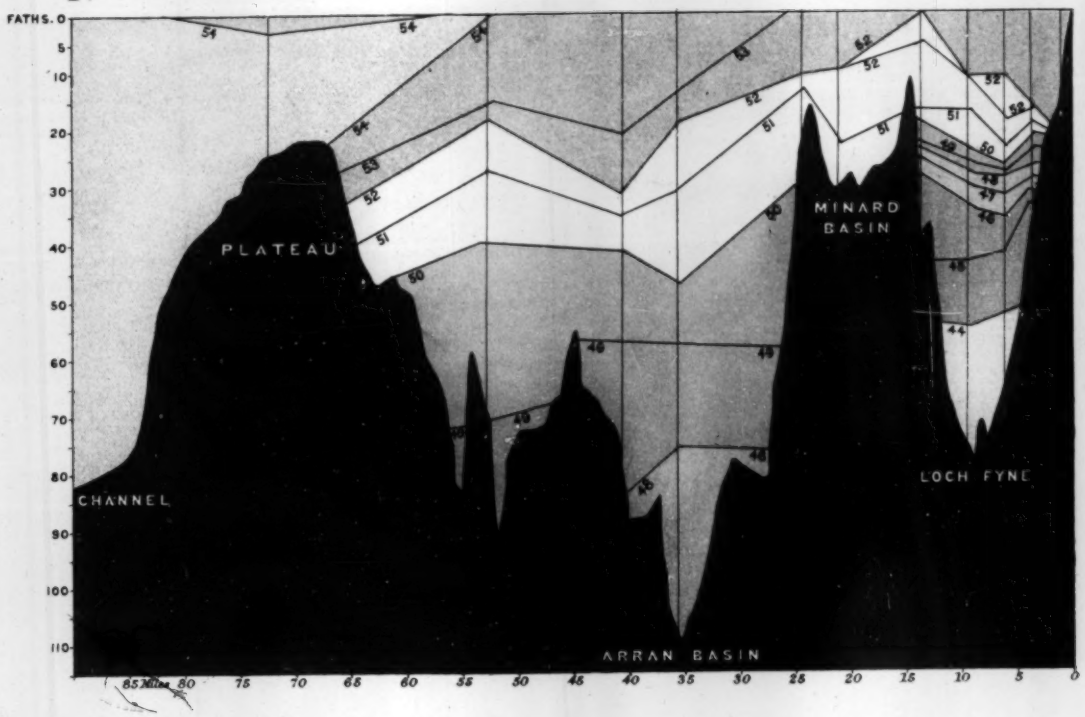
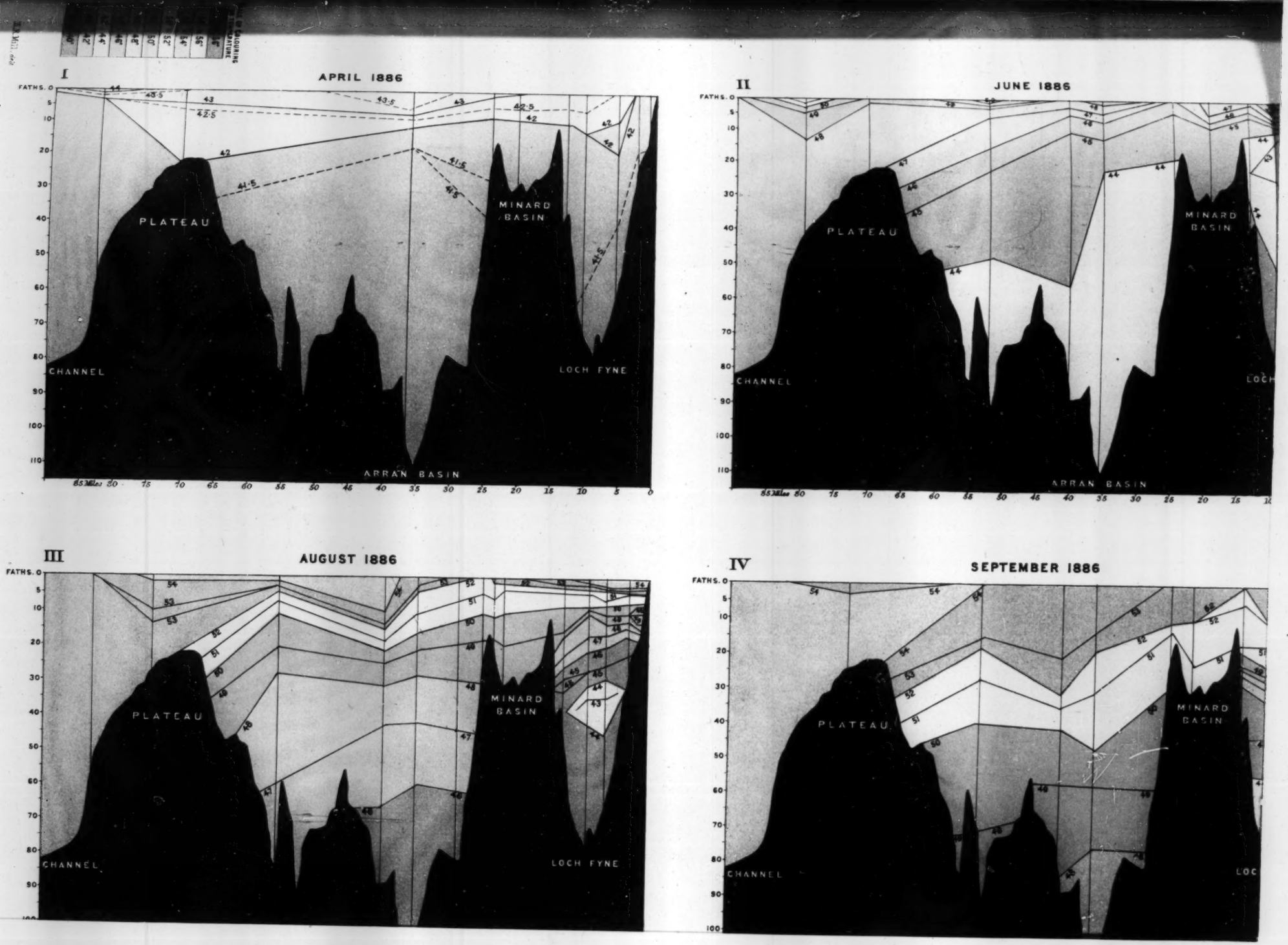
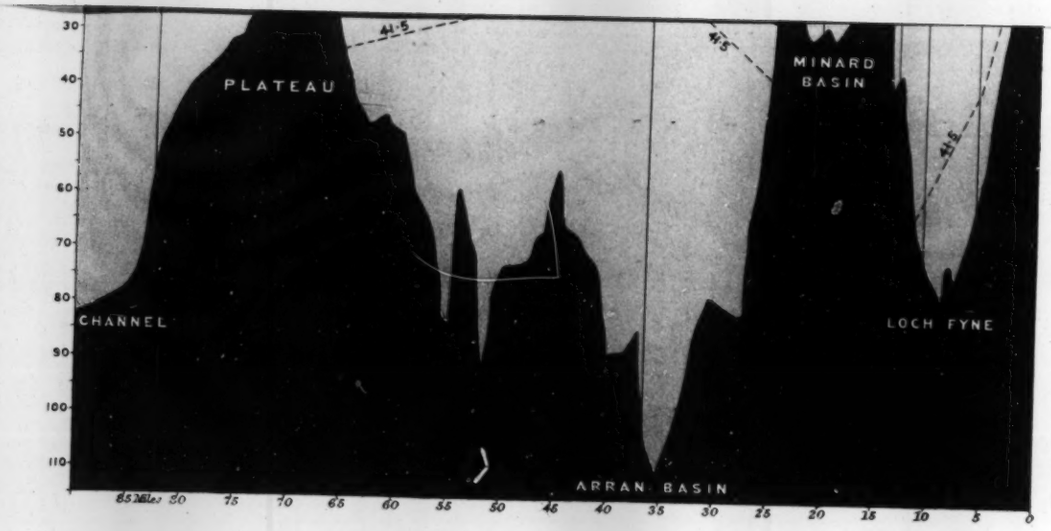
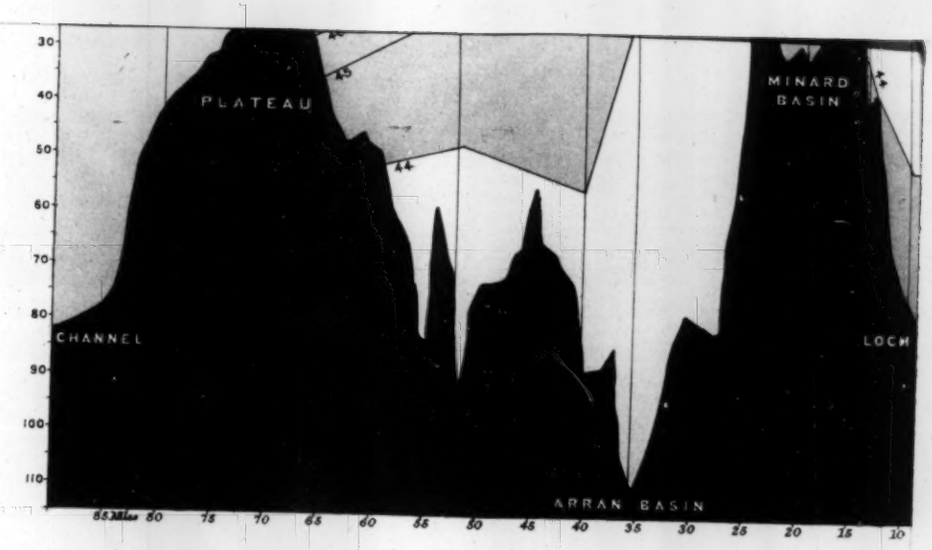


PLATE VIII


I
APRIL 1886
FATHS.
PLATEAU
MINARD BASIN
CHANNEL
LOCH FYNE
ARRAN BASIN
II
JUNE 1886
PLATEAU
MINARD BASIN
CHANNEL
ARRAN BASIN
III
AUGUST 1886
PLATEAU
MINARD BASIN
CHANNEL
LOCH FYNE
IV
SEPTEMBER 1886
PLATEAU
MINARD BASIN
CHANNEL





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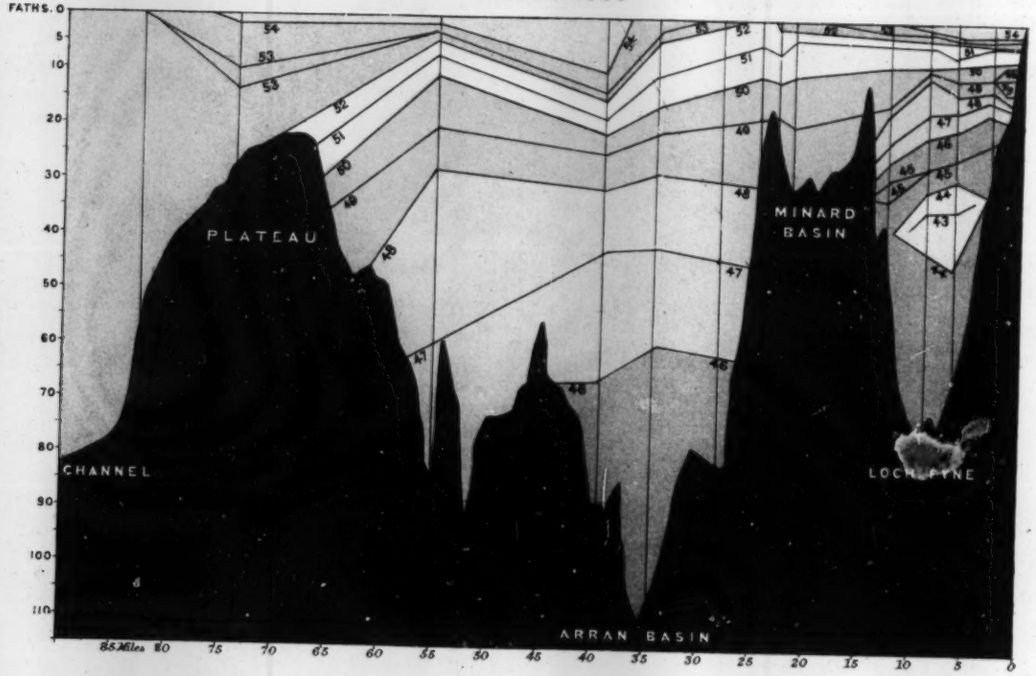

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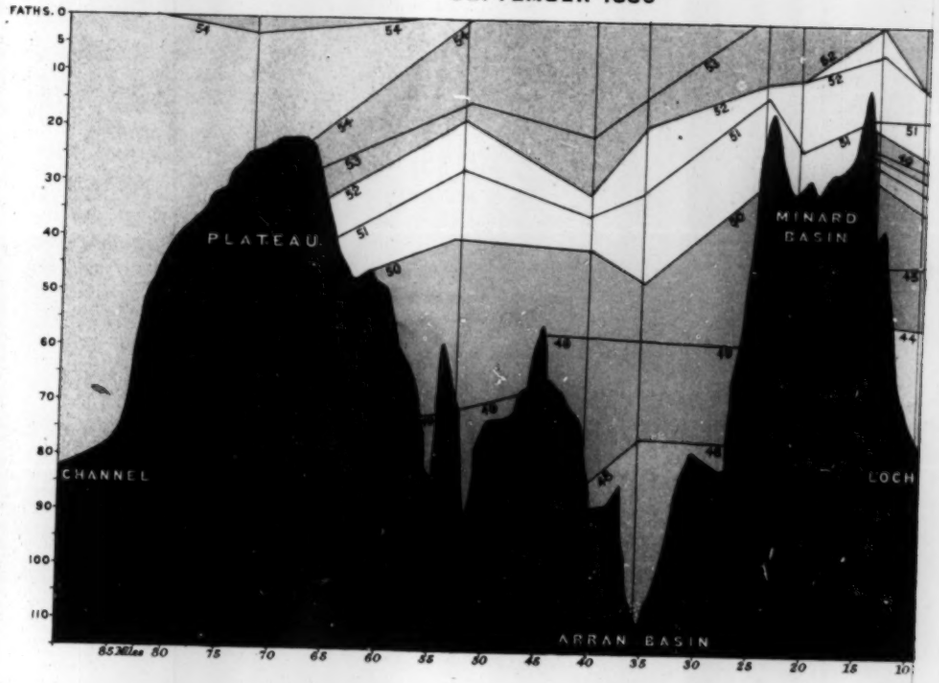


Bartholomew Edinr

TEMPERATURE SECTIONS OF CLYDE SEA AREA

FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE

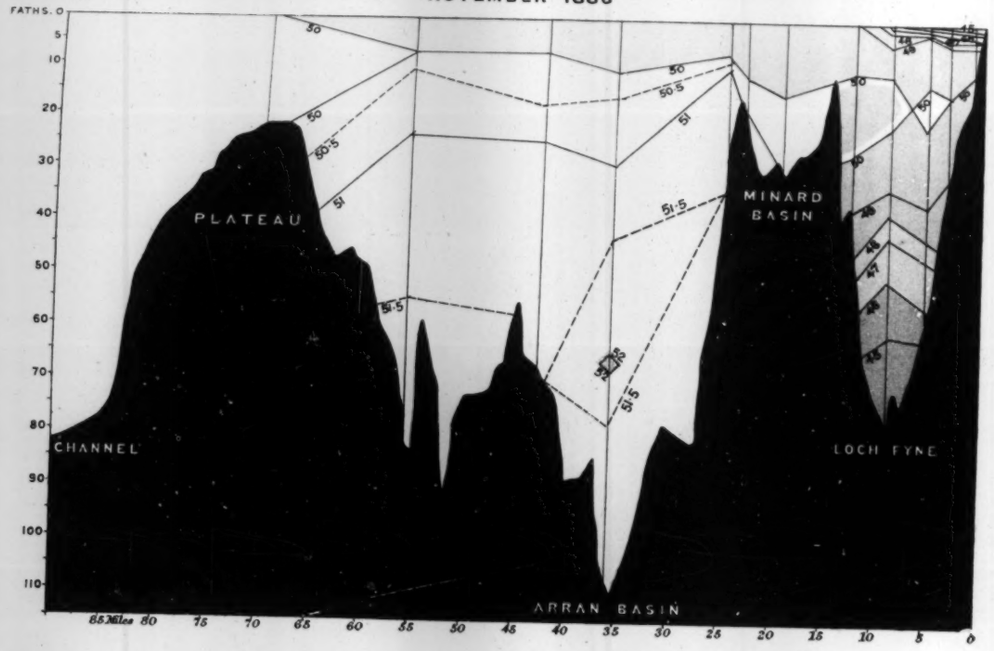
TEMPERATURE SECTIONS OF CLYDE SEA AREA

FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE

H.R. Mill del.

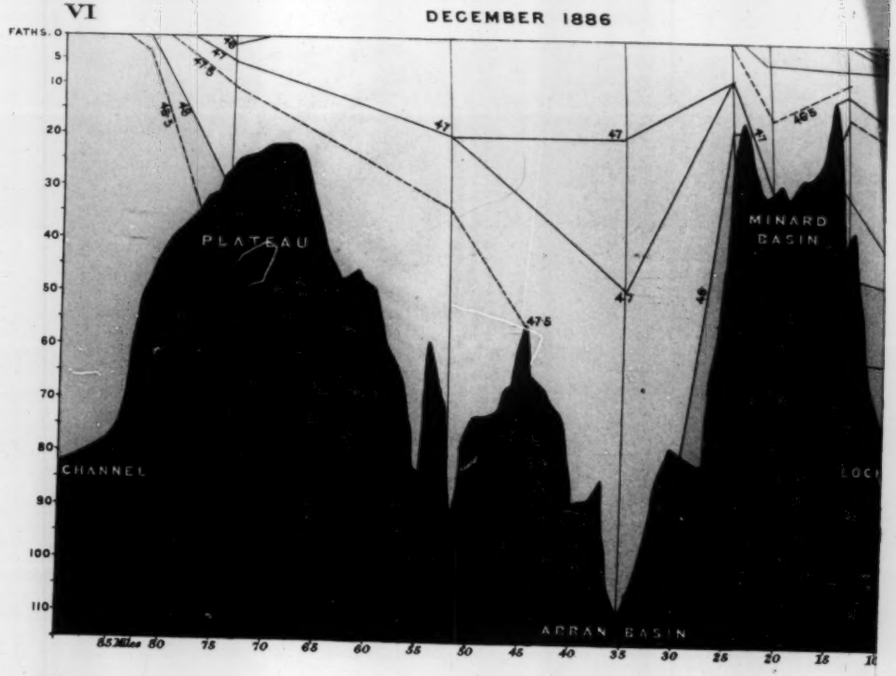
V

NOVEMBER 1886



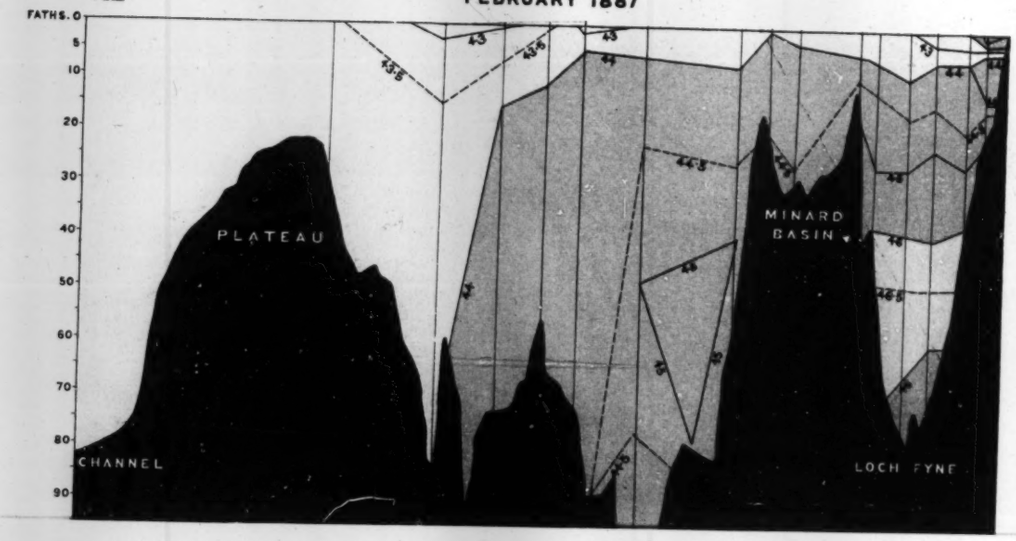
VI

DECEMBER 1886



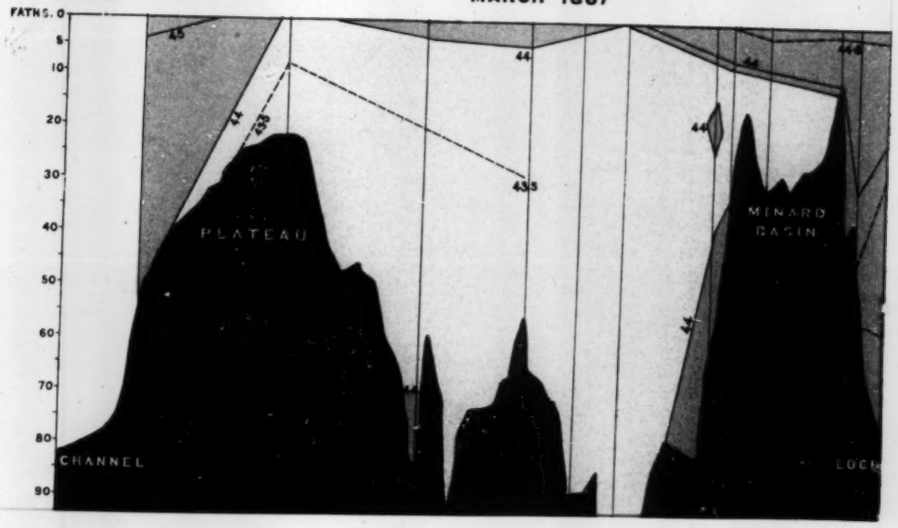
VII

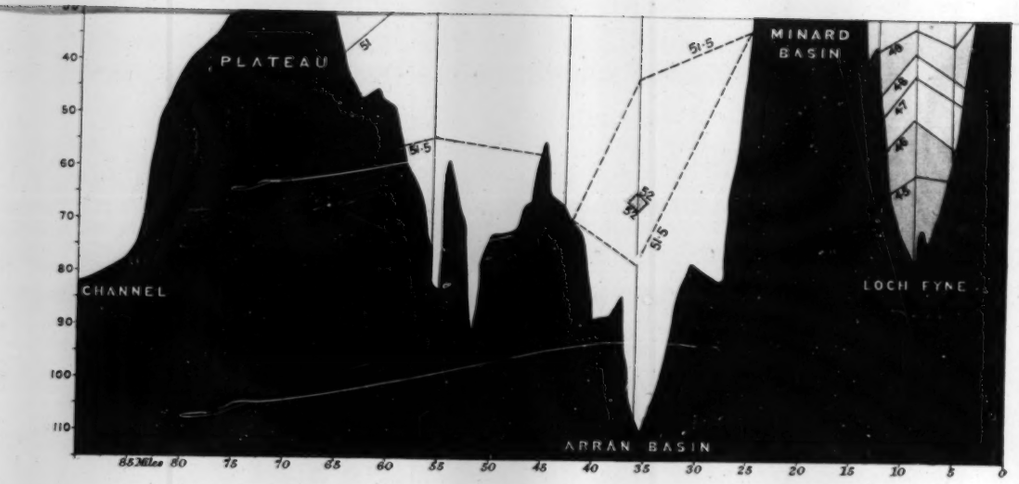
FEBRUARY 1887

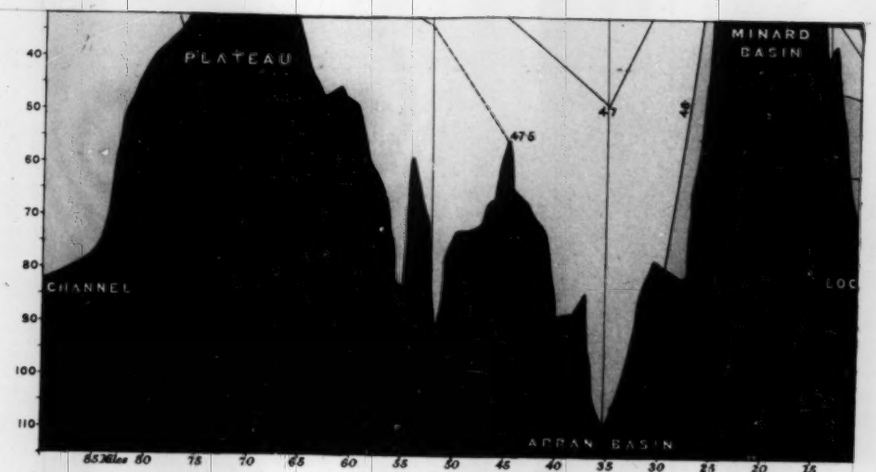


VIII

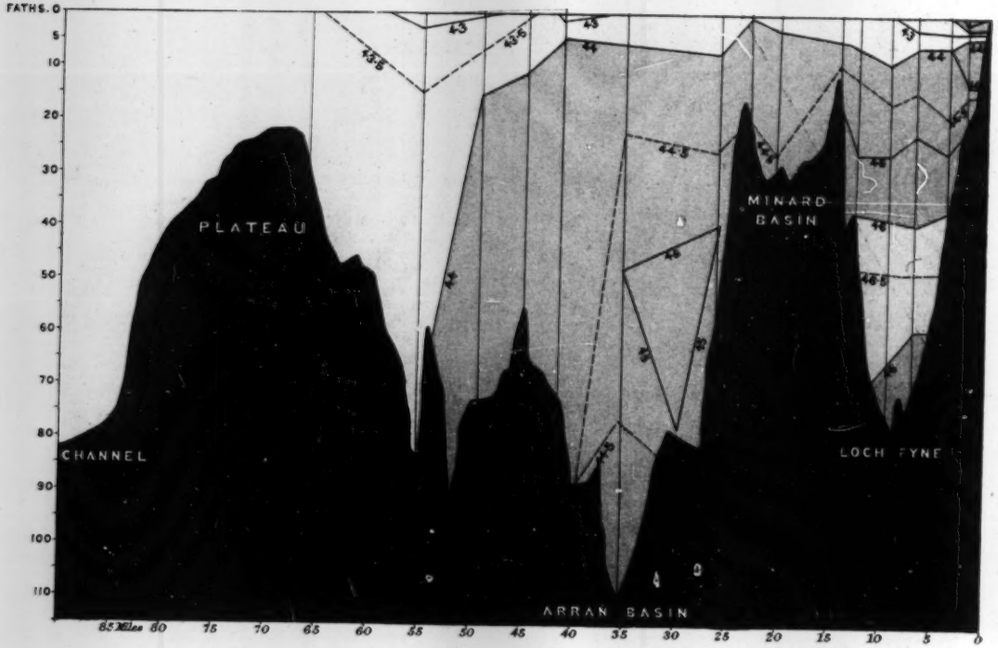
MARCH 1887



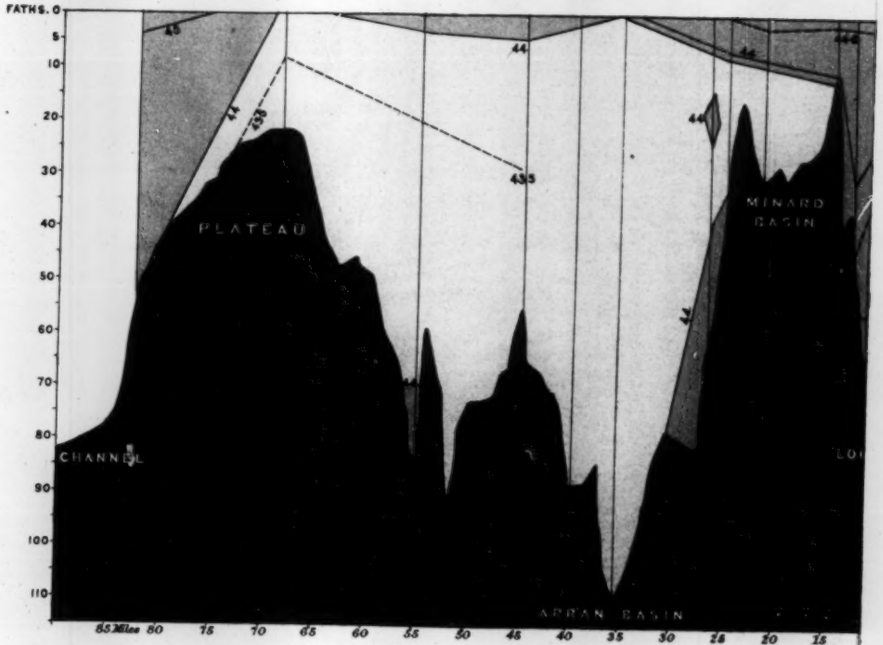




VII FEBRUARY 1887



VIII MARCH 1887



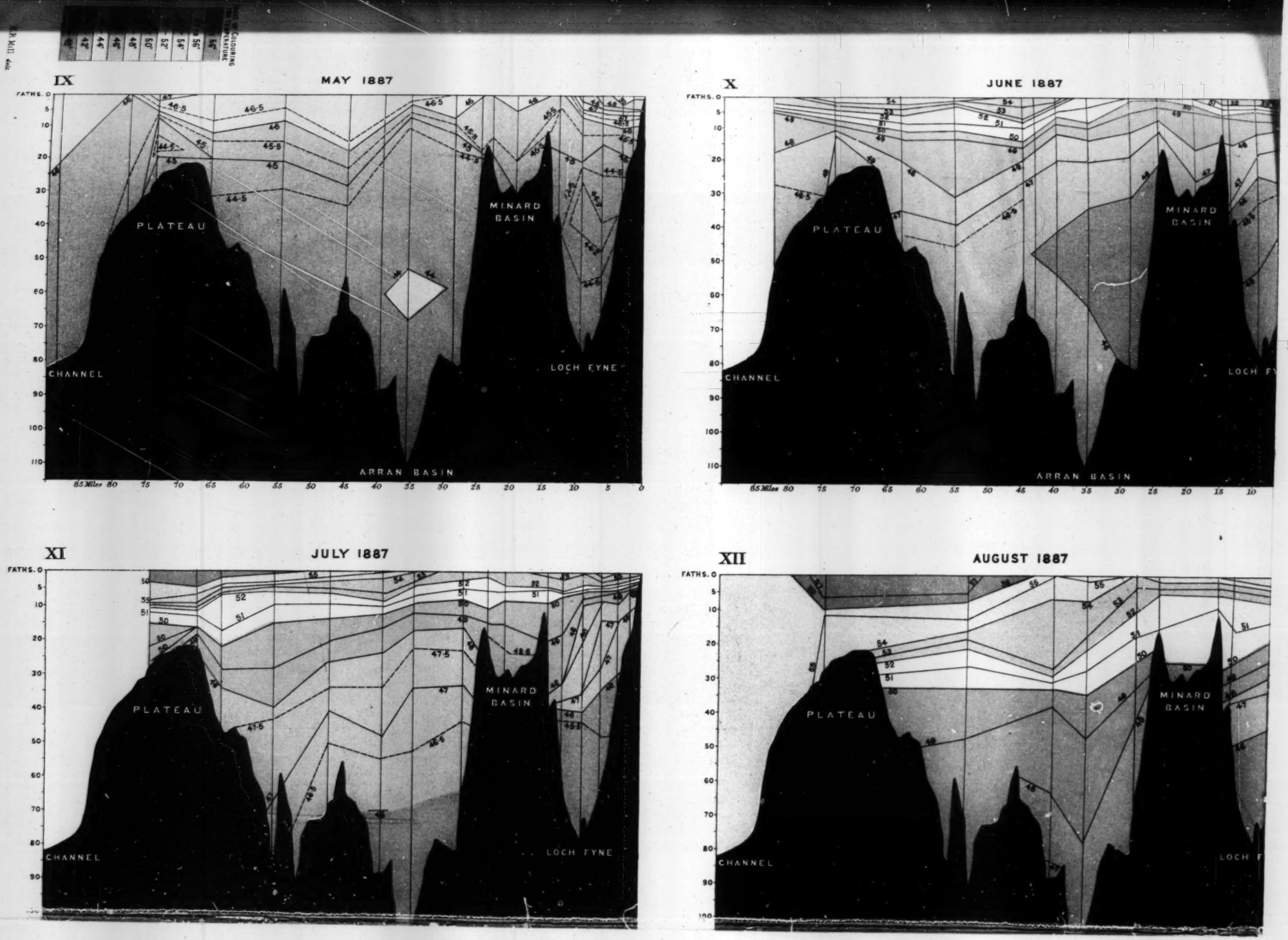
Bartholomew, Edin.

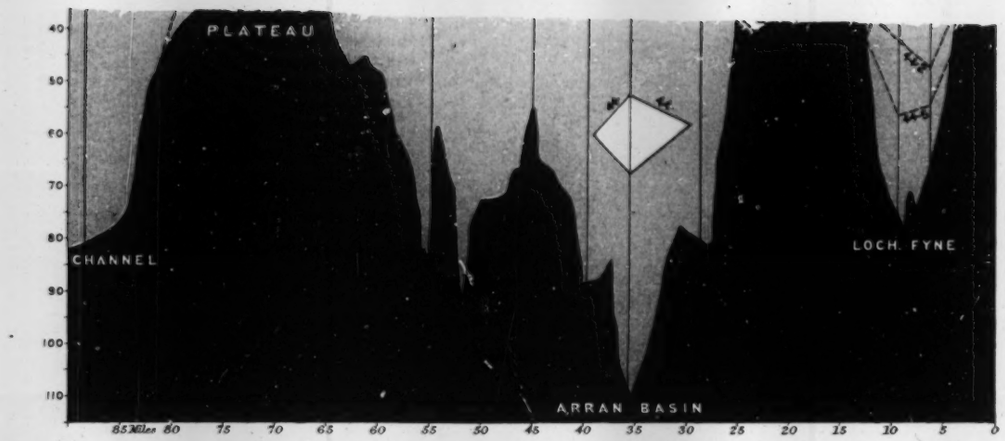
TEMPERATURE SECTIONS OF CLYDE SEA AREA

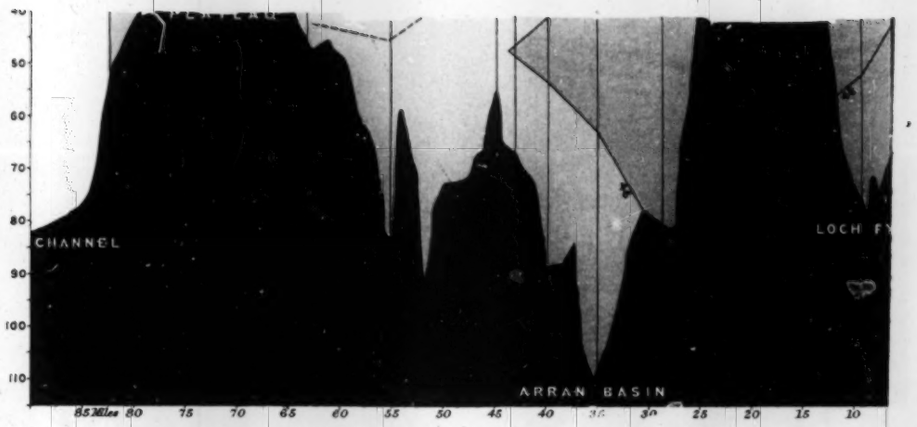
FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE

TEMPERATURE SECTIONS OF CLYDE SEA AREA

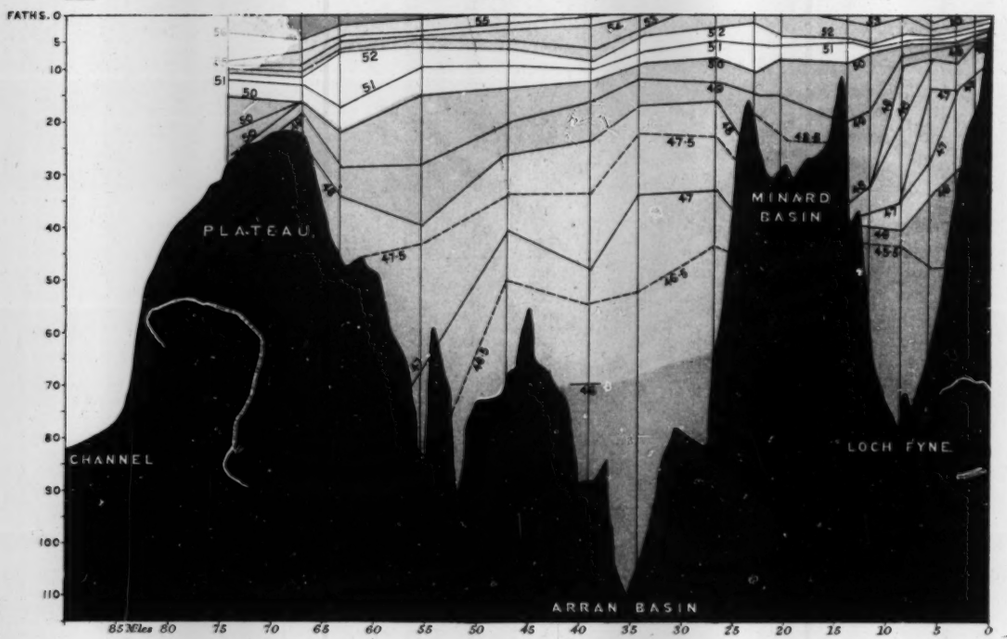
FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE


IX
MAY 1887
FATHS. 0
PLATEAU
MINARD BASIN
CHANNEL
LOCH FYNE
ARRAN BASIN
85 Miles 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
X
JUNE 1887
FATHS. 0
PLATEAU
MINARD BASIN
CHANNEL
ARRAN BASIN
85 Miles 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10
XI
JULY 1887
FATHS. 0
PLATEAU
MINARD BASIN
CHANNEL
LOCH FYNE
XII
AUGUST 1887
FATHS. 0
PLATEAU
MINARD BASIN
CHANNEL

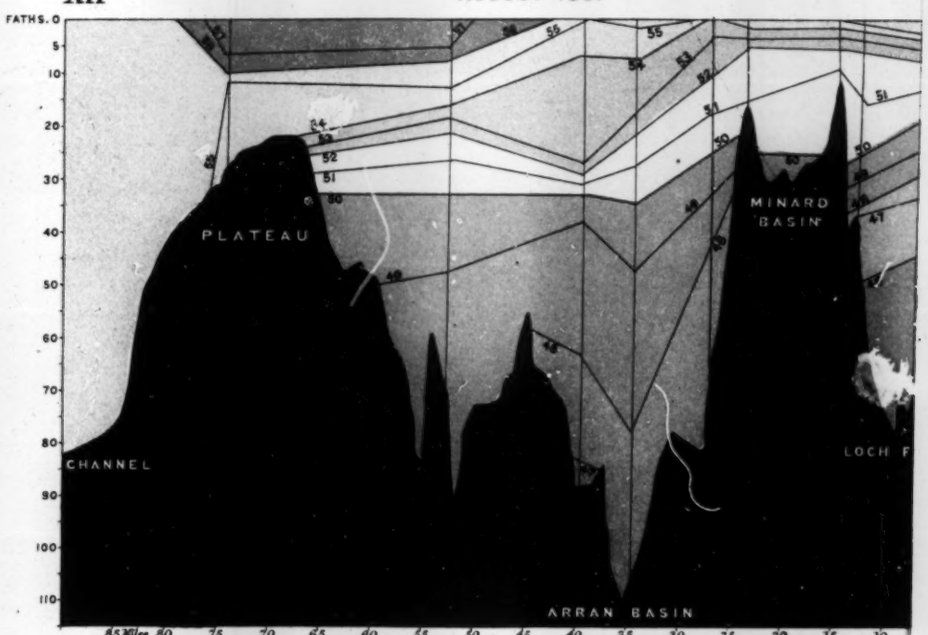




XI JULY 1887



XII AUGUST 1887

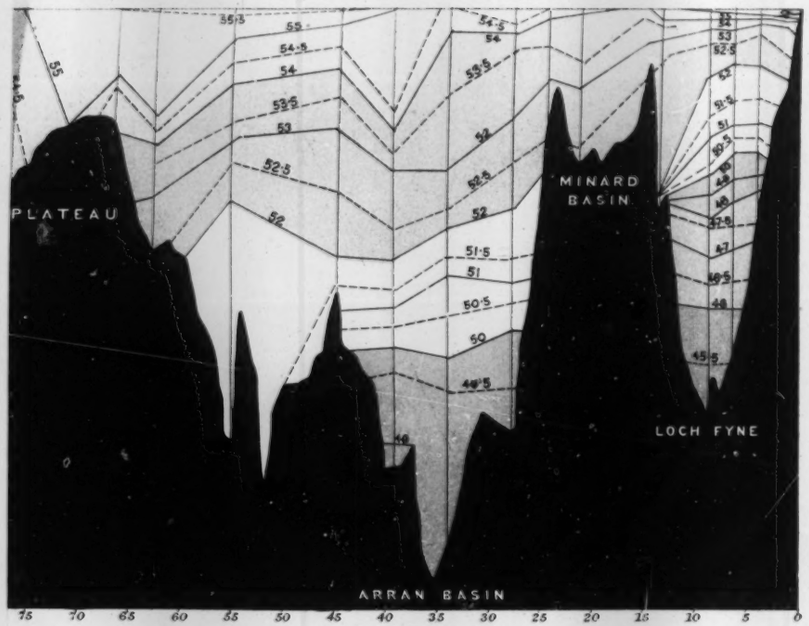


Bartholomew, Edin.

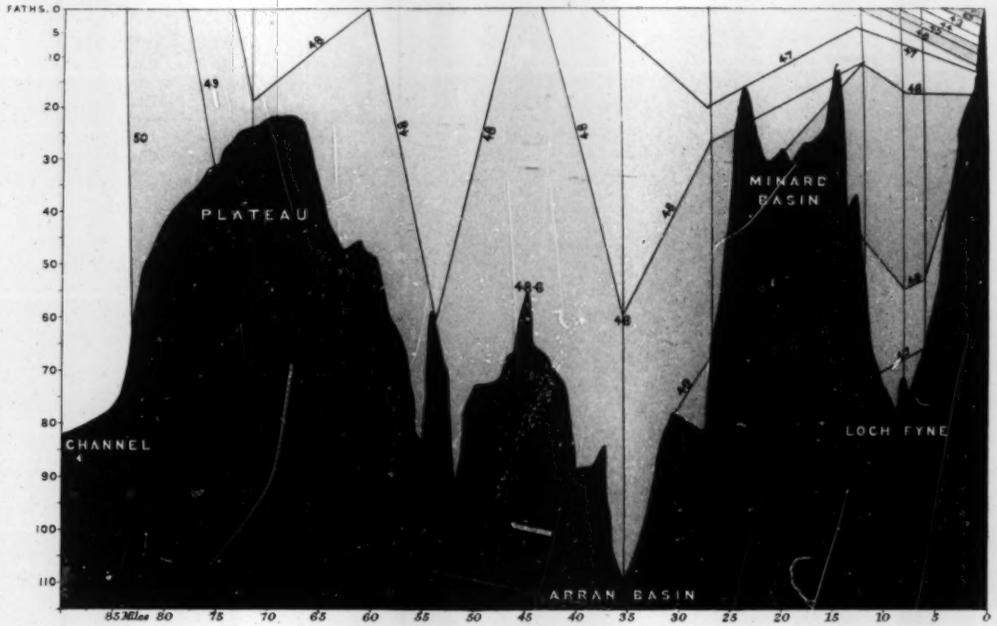
TEMPERATURE SECTIONS OF CLYDE SEA AREA

FROM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL. LOCH FYNE

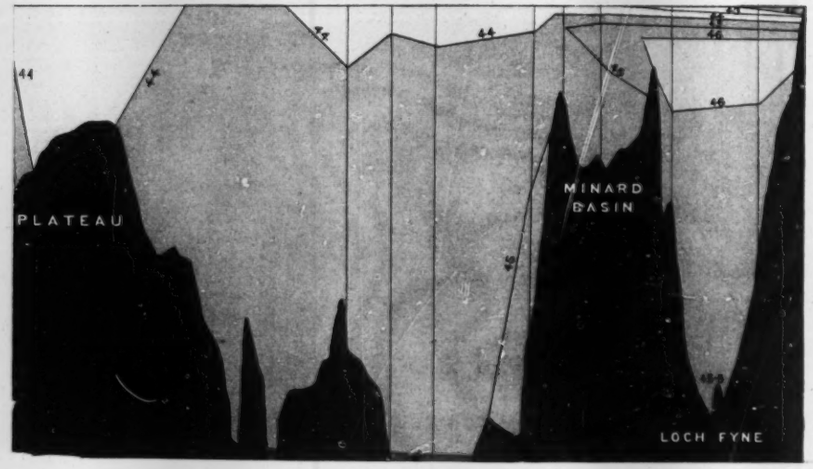
SEPTEMBER 1887



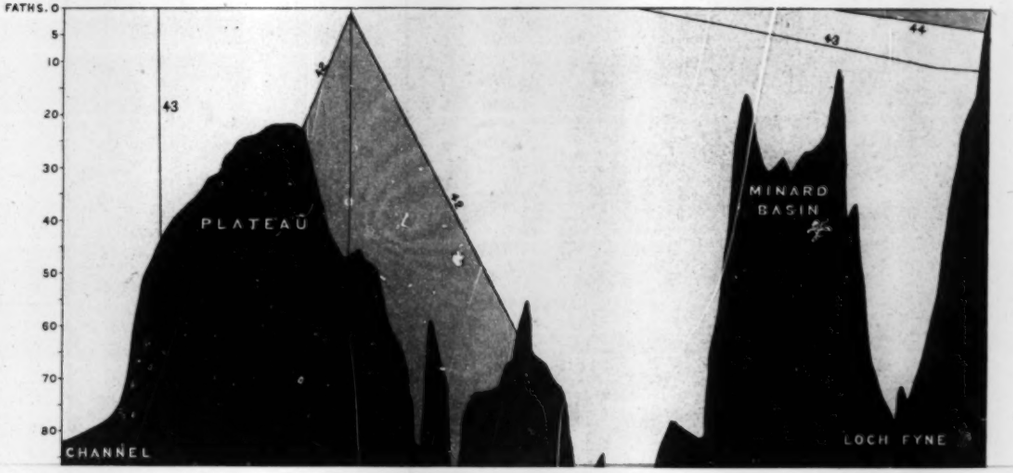
DECEMBER 1887



FEBRUARY 1888



APRIL 1888

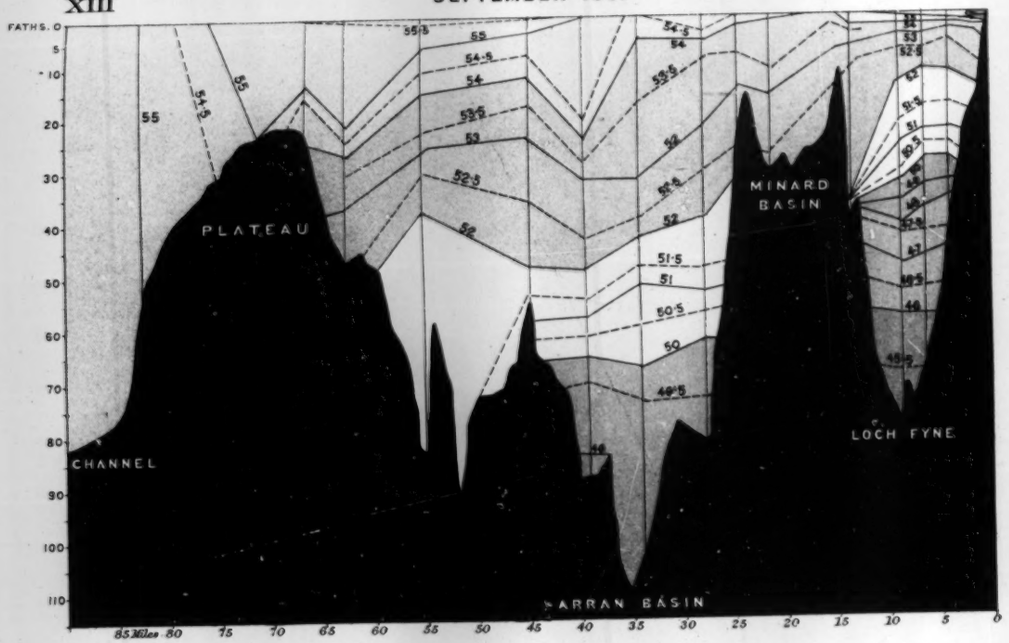


TEMPERATURE SECTIONS OF CLYDE SEA AREA

OM THE CHANNEL THROUGH THE WEST AND CENTRAL ARRAN BASINS TO CUILL, LOCH FYNE

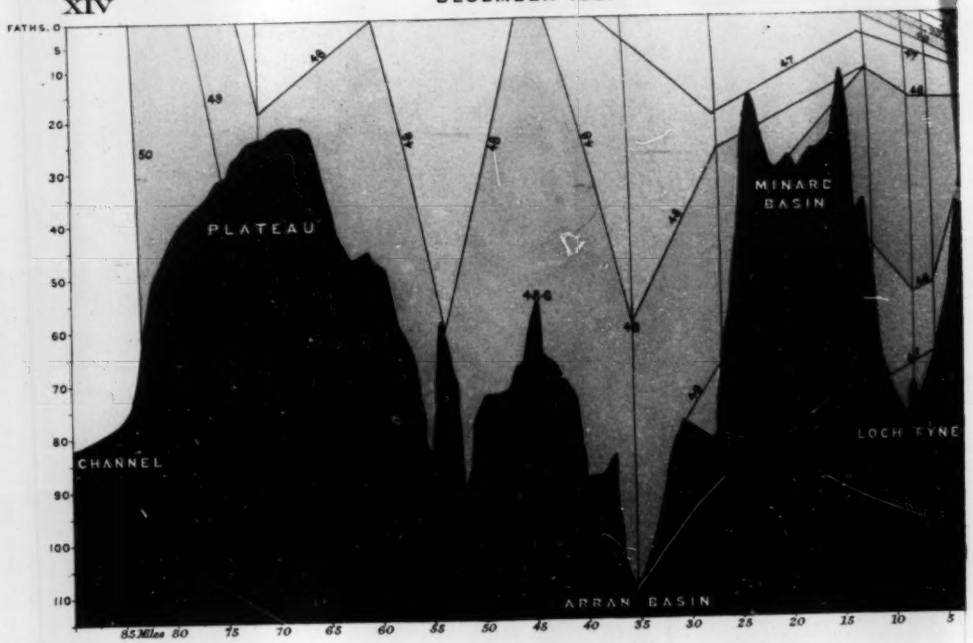
XIII

SEPTEMBER 1887



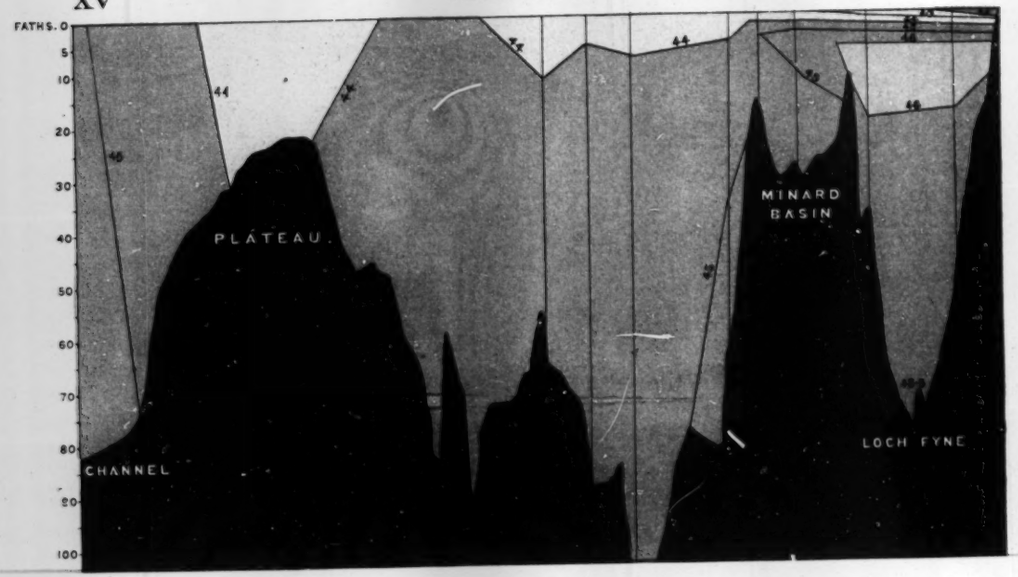
XIV

DECEMBER 1887



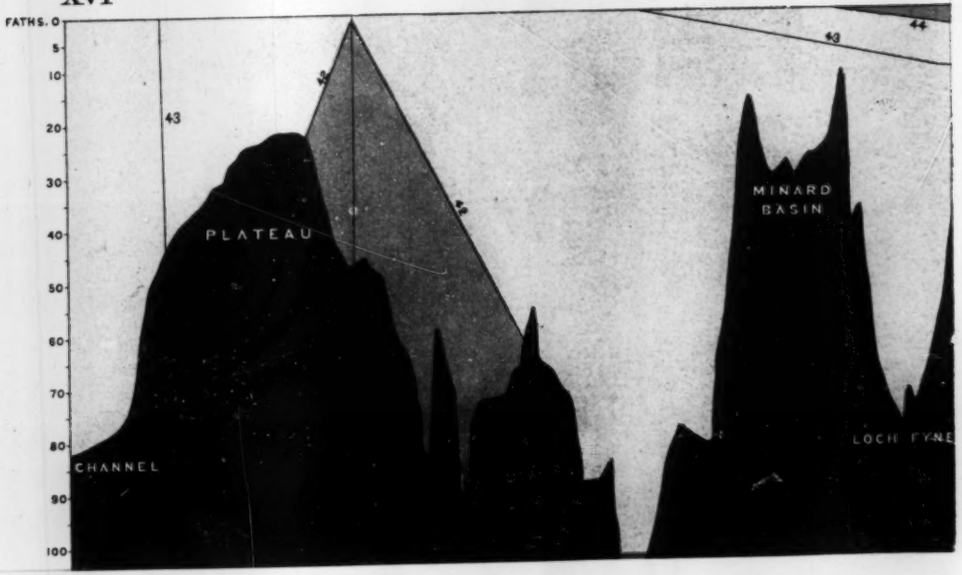
XV

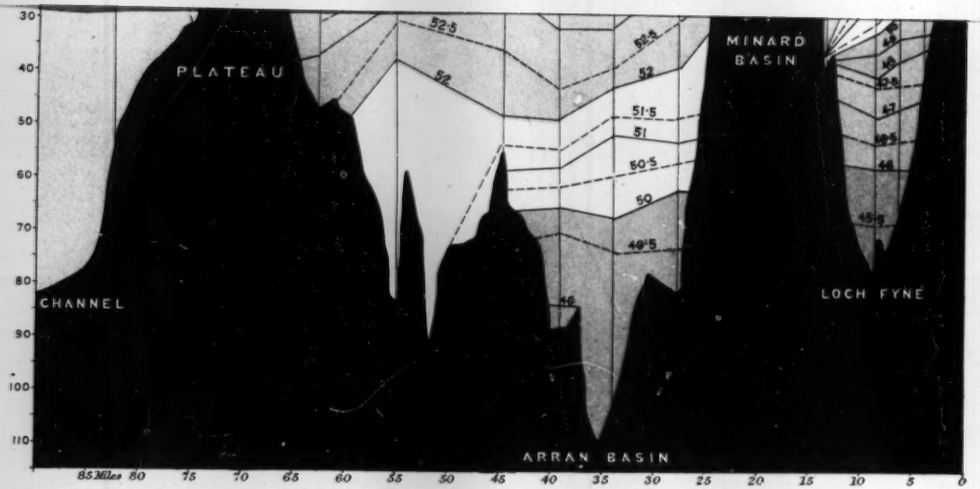
FEBRUARY 1888

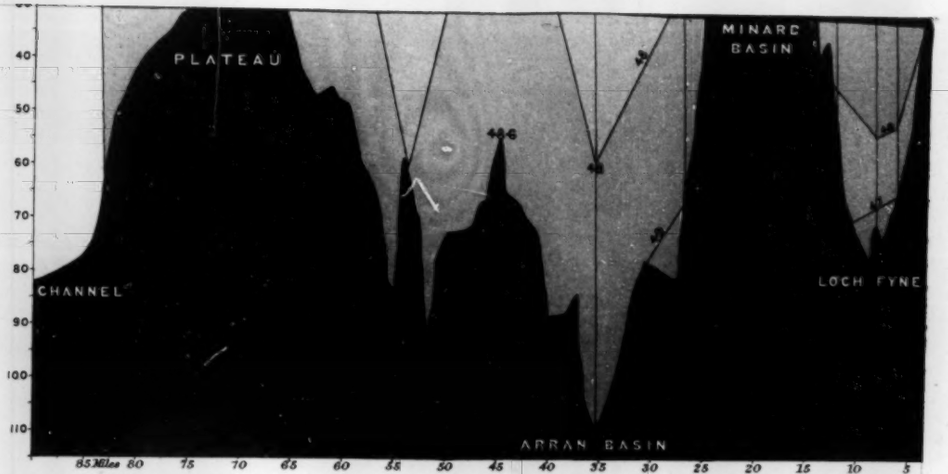


XVI

APRIL 1888

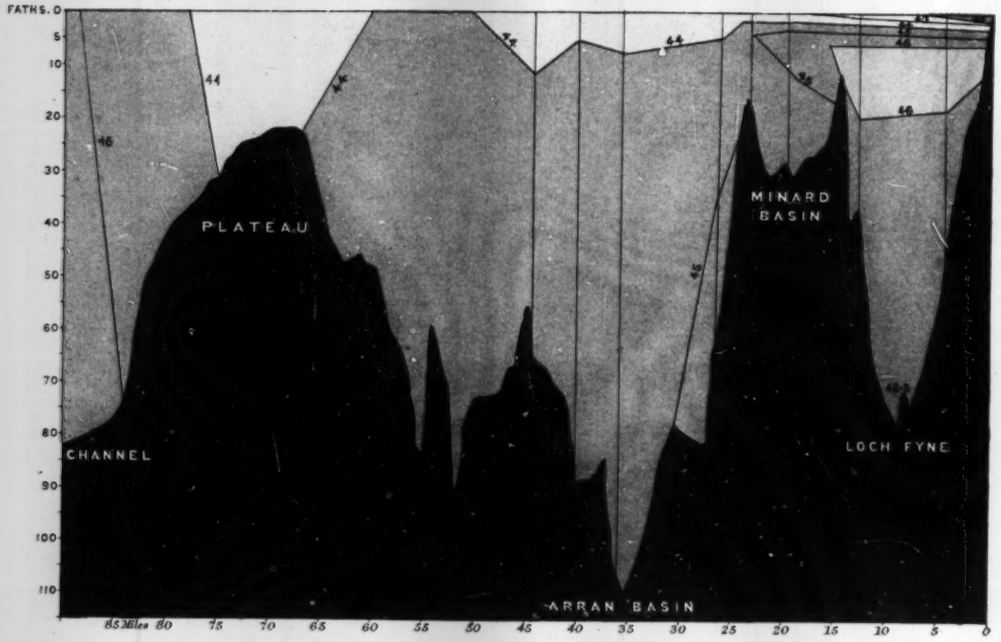






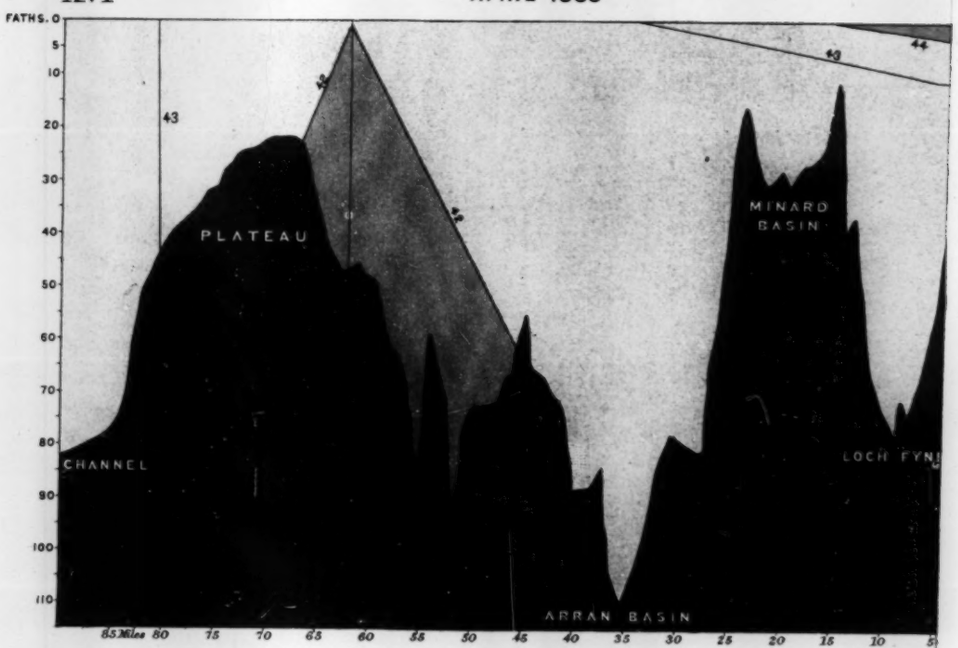
XV

FEBRUARY 1888



XVI

APRIL 1888



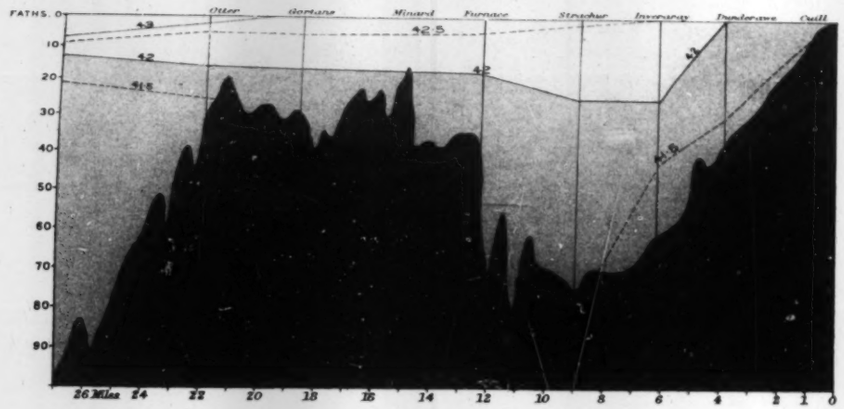
Bartholomew, Edin.r

TEMPERATURE SECTIONS OF LOCH FYNE

TEMPERATURE SECTIONS OF LOCH FYNE

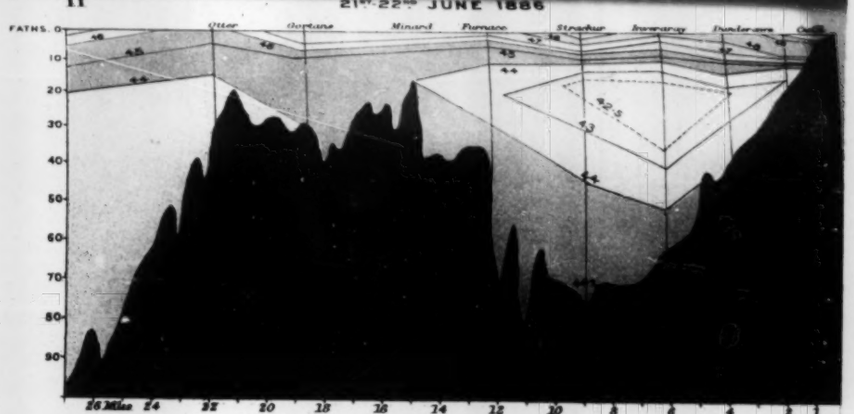
I

20TH APRIL 1886



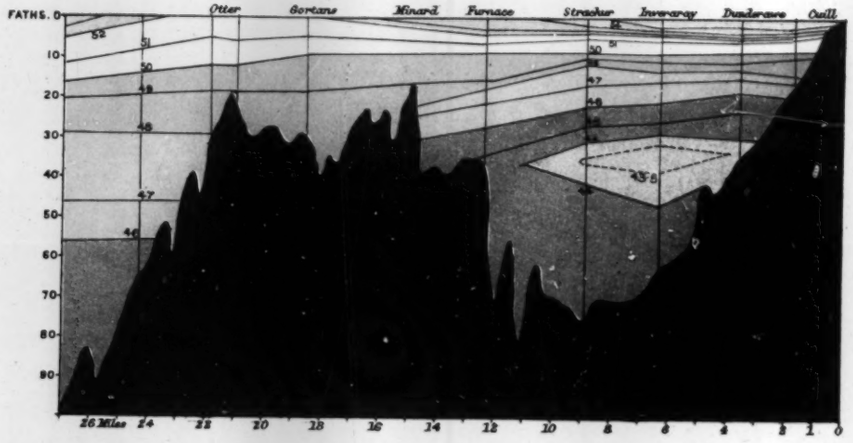
II

21ST-22ND JUNE 1886



III

10TH-11TH AUGUST 1886

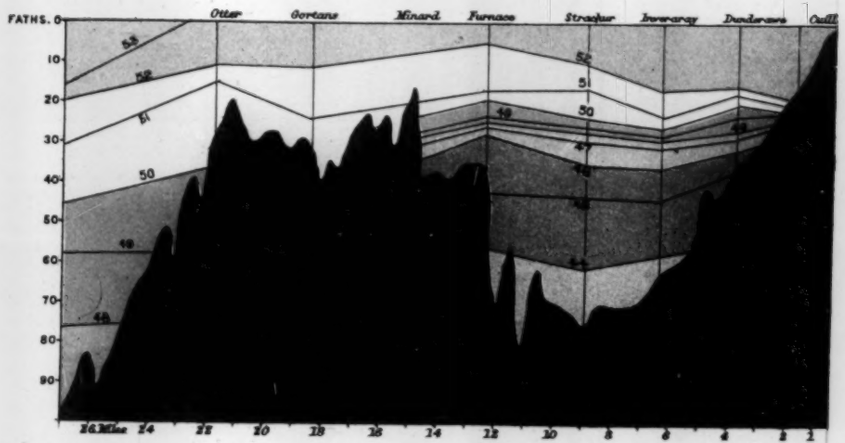


SCALE OF COLOURING FOR TEMPERATURE

ABOVE 54°
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°

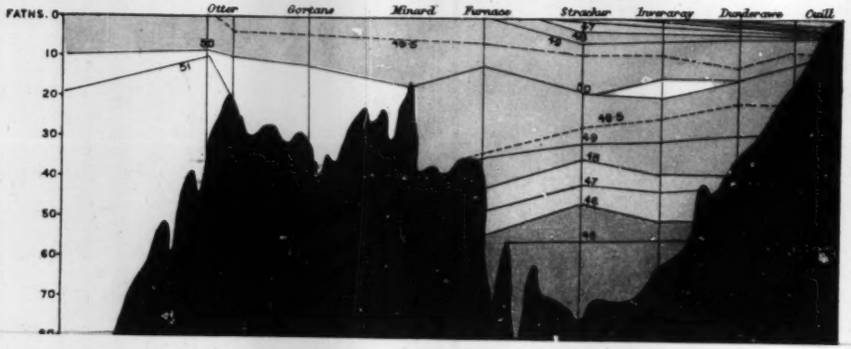
IV

27TH-28TH SEPTEMBER 1886



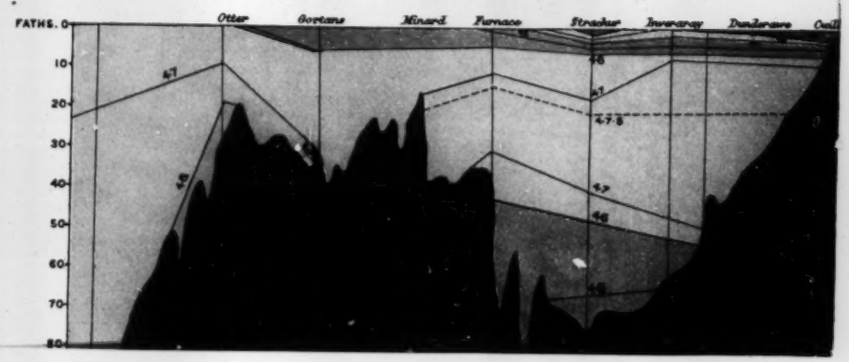
V

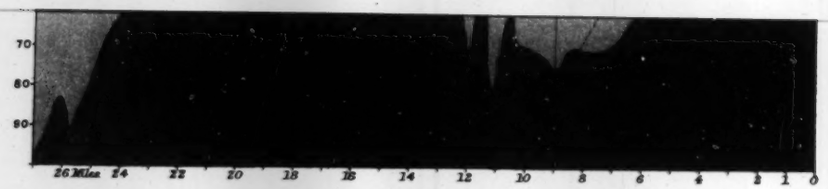
16TH-17TH NOVEMBER 1886



VI

29TH-30TH DECEMBER 1886



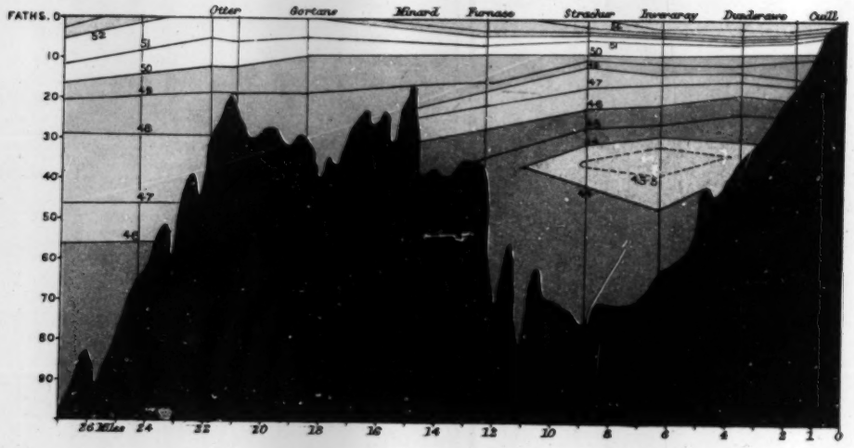


SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°

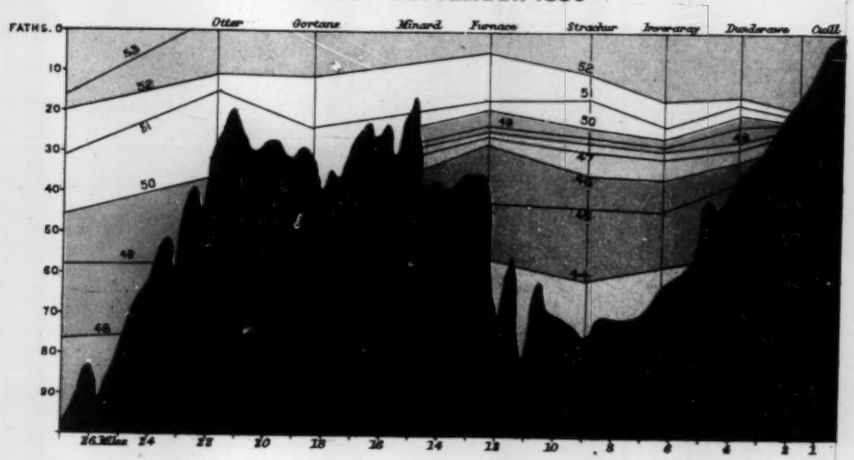
III

10TH-11TH AUGUST 1886



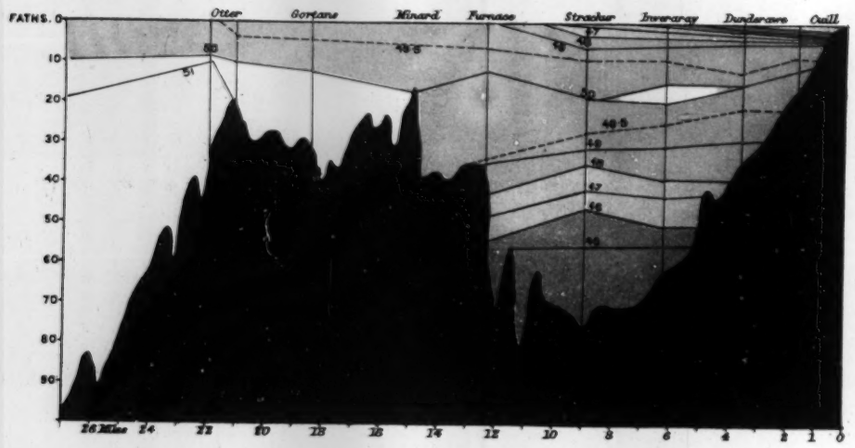
IV

27TH-28TH SEPTEMBER 1886



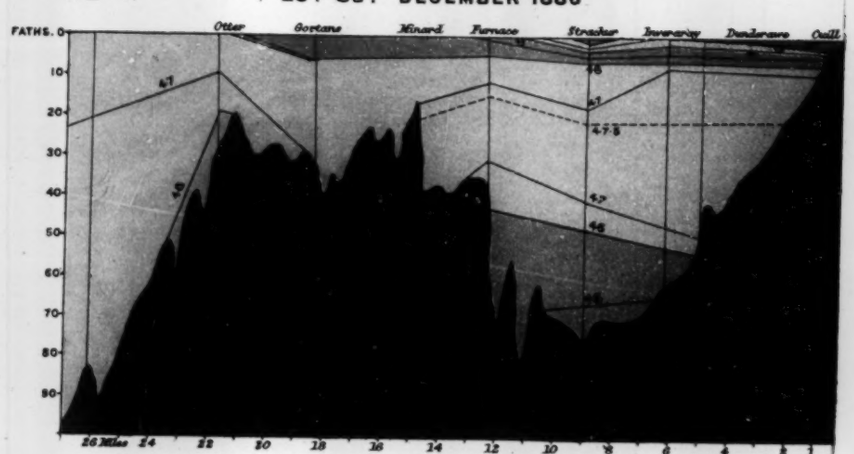
V

16TH-17TH NOVEMBER 1886



VI

29TH-30TH DECEMBER 1886



Bartholomew Edin.r

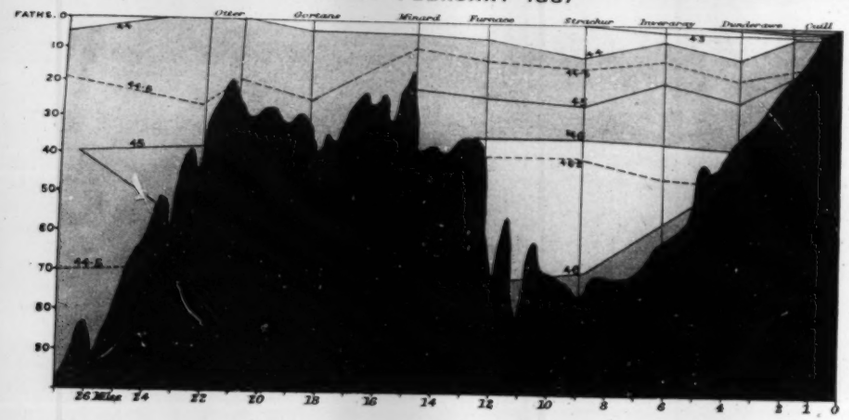
TEMPERATURE SECTIONS OF LOCH FYNE

TEMPERATURE SECTIONS OF LOCH FYNE

H.R.M.S. 454

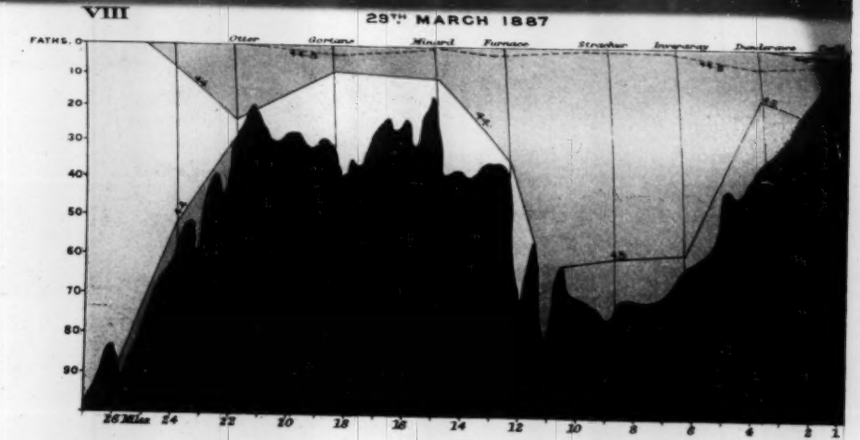
VII

4TH-5TH FEBRUARY 1887



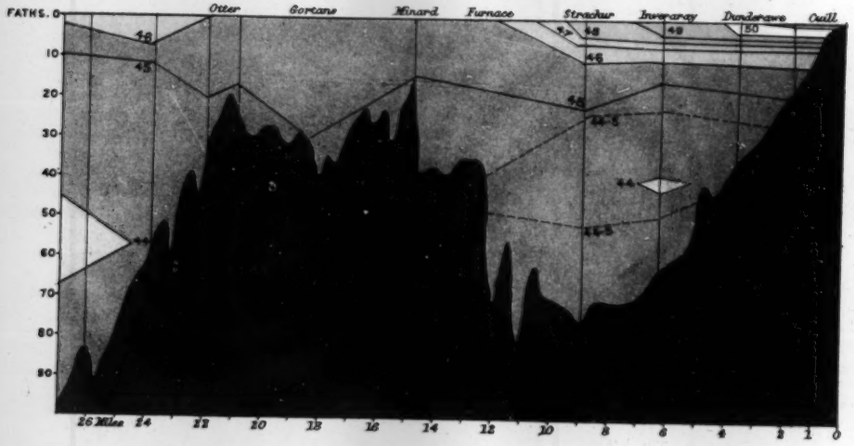
VIII

28TH MARCH 1887



IX

10TH MAY 1887

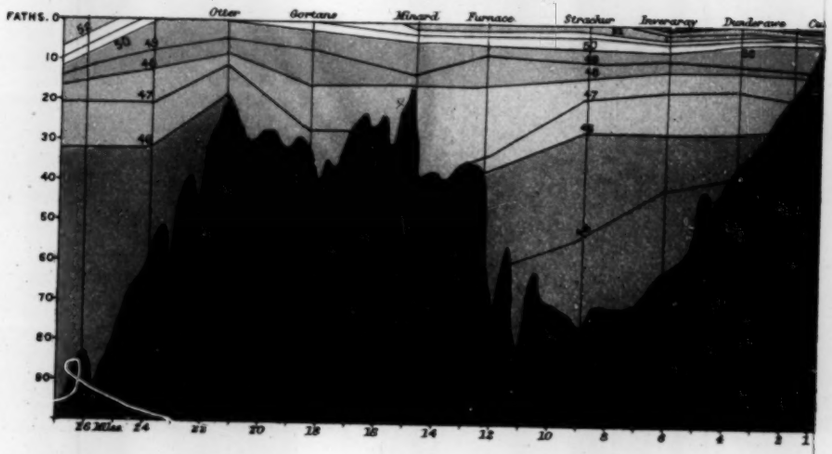


SCALE OF COLOURING FOR TEMPERATURE

Above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°

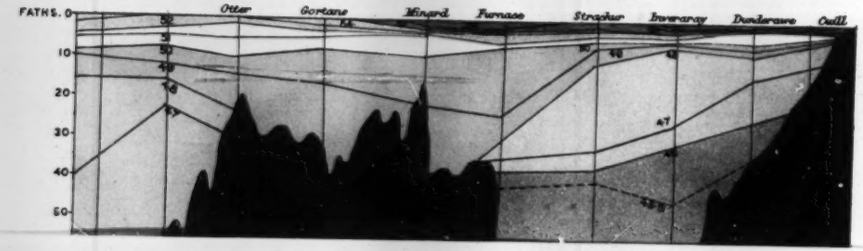
X

15TH-16TH JUNE 1887



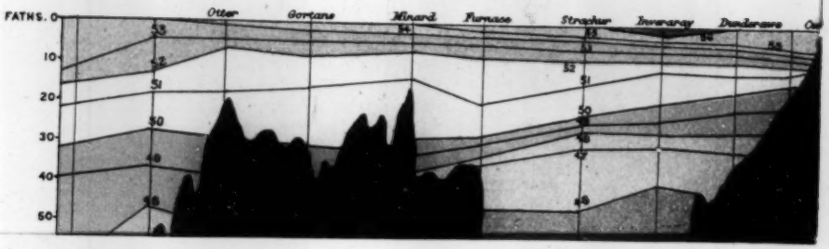
XI

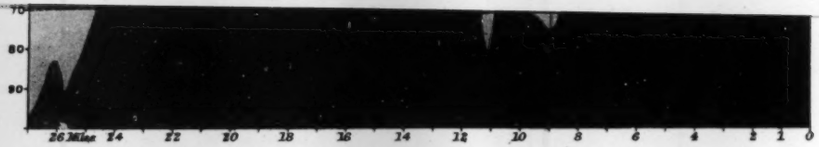
7TH 8TH JULY 1887

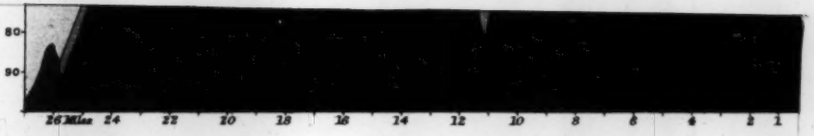


XII

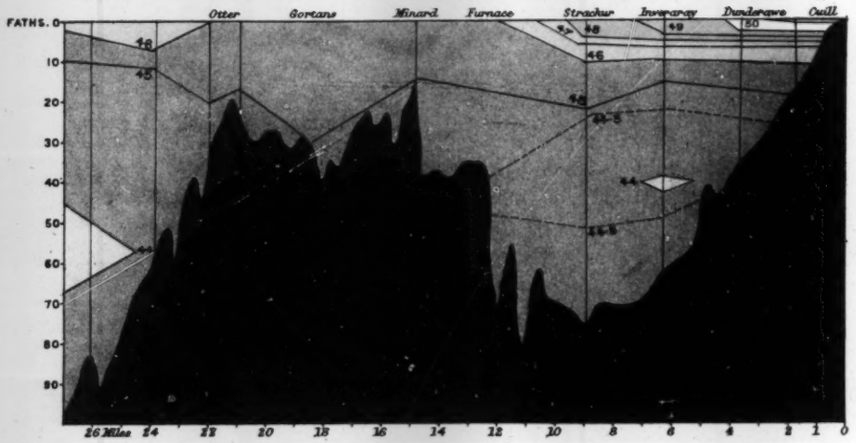
15TH-16TH AUGUST 1887



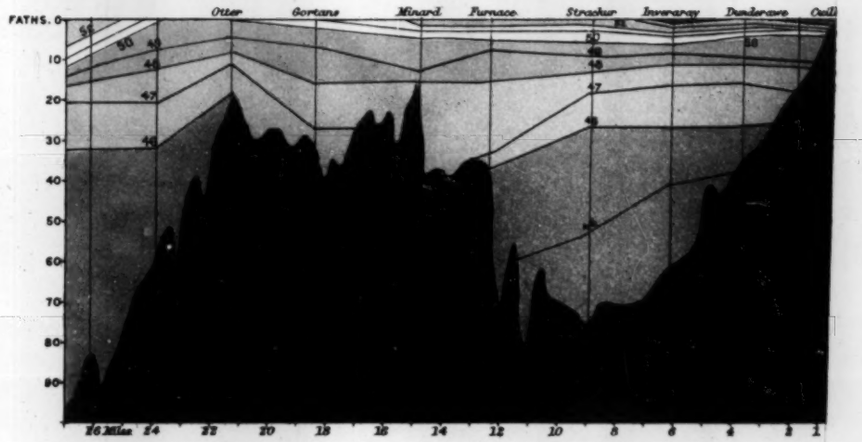




IX 10TH MAY 1887



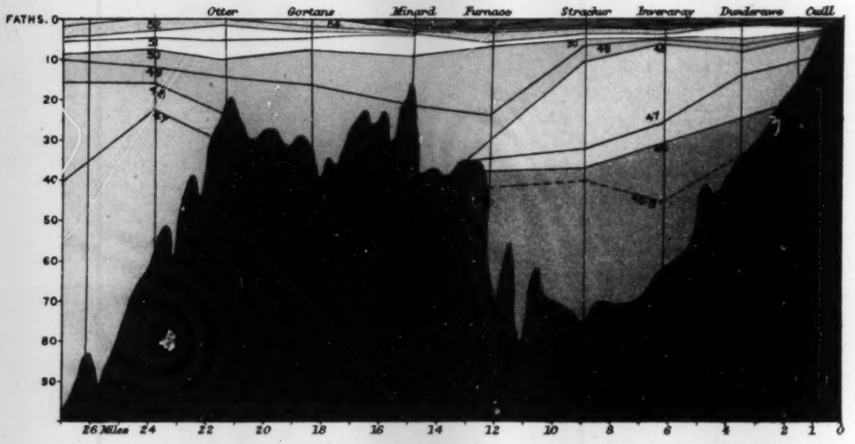
X 15TH-16TH JUNE 1887



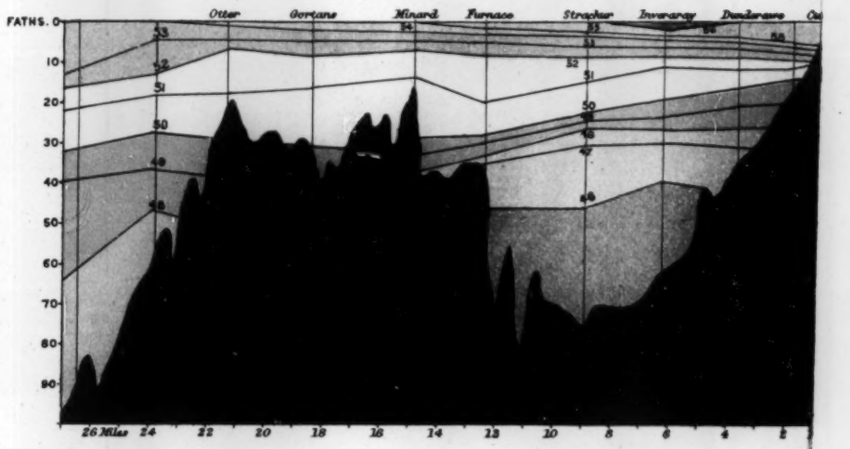
SCALE OF COLOURING FOR TEMPERATURE

above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°

XI 7TH 8TH JULY 1887



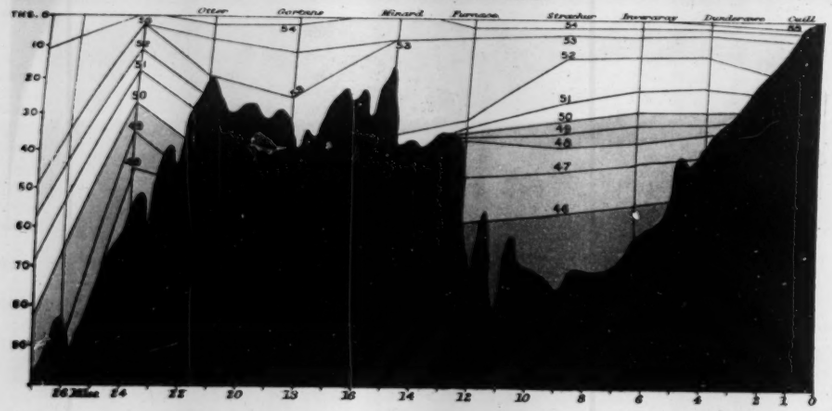
XII 15TH-16TH AUGUST 1887



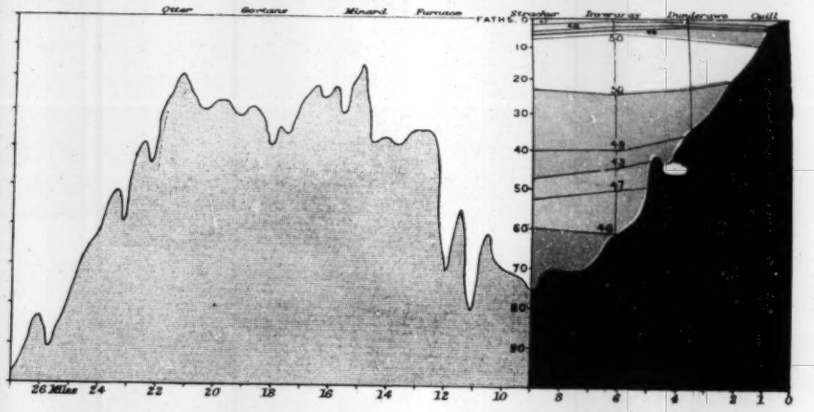
Bartholomew Edin.

TEMPERATURE SECTIONS OF LOCH FYNE

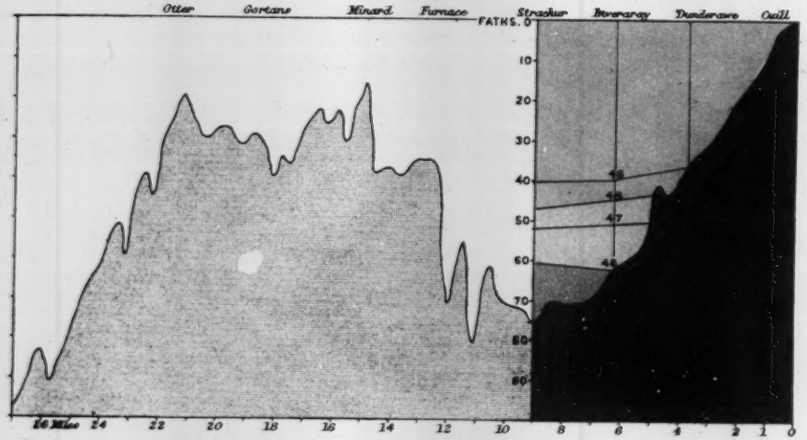
XIII 25TH SEPTEMBER 1887



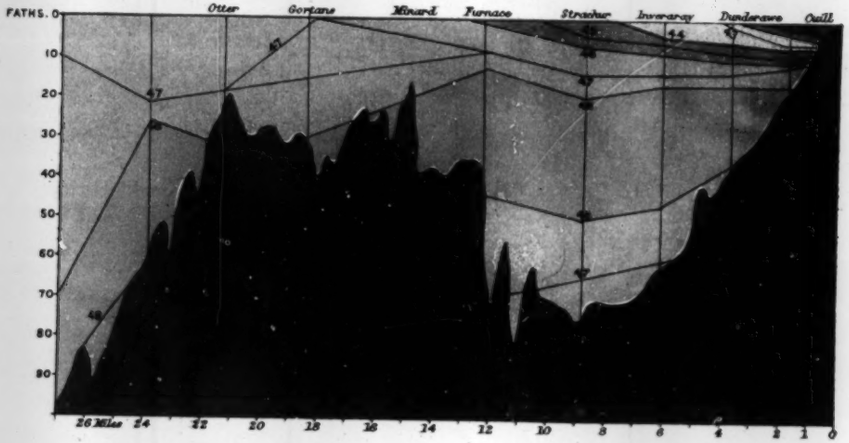
XIV 5TH NOVEMBER 1887



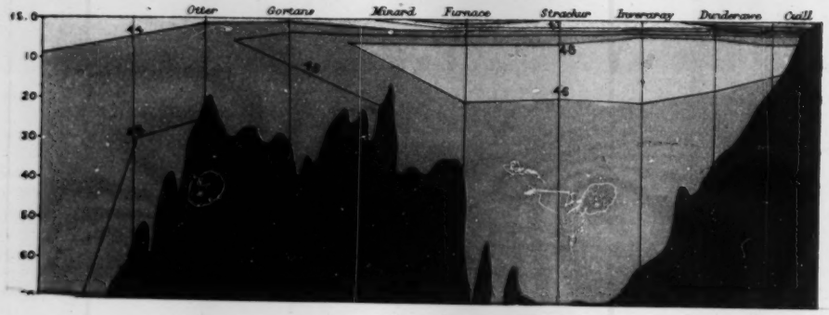
XV 7TH NOVEMBER 1887



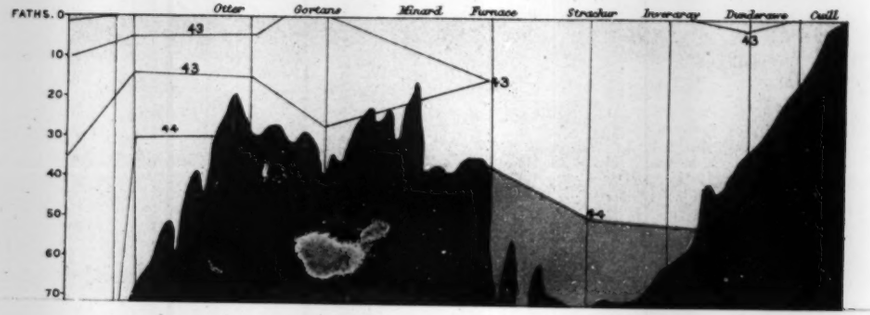
XVI 16TH-17TH DECEMBER 1887



XVII 14TH FEBRUARY 1888

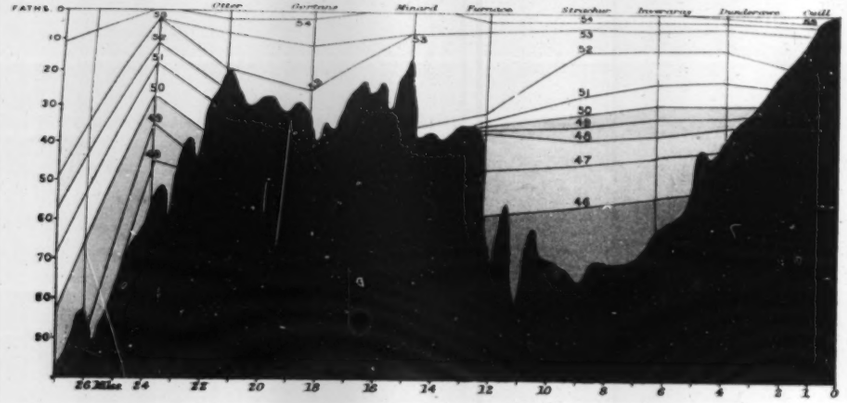


XVIII 22ND-23RD MARCH 1888

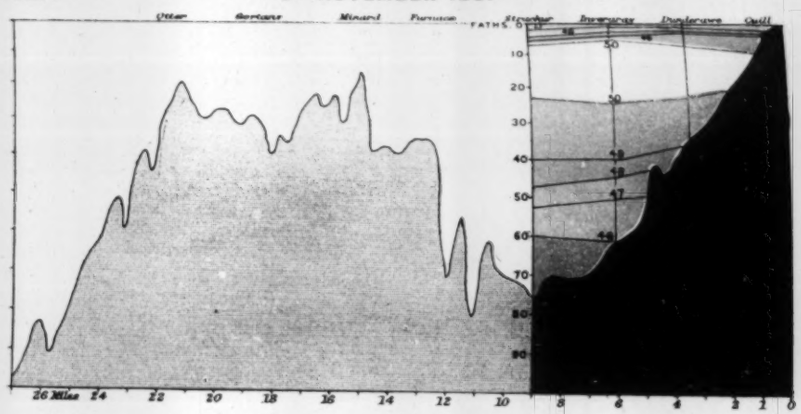


TEMPERATURE SECTIONS OF LOCH FYNE

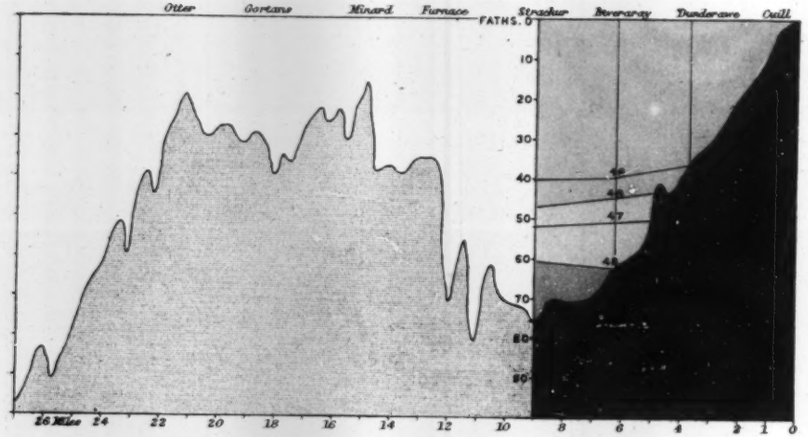
XIII 25TH SEPTEMBER 1887



XIV 5TH NOVEMBER 1887



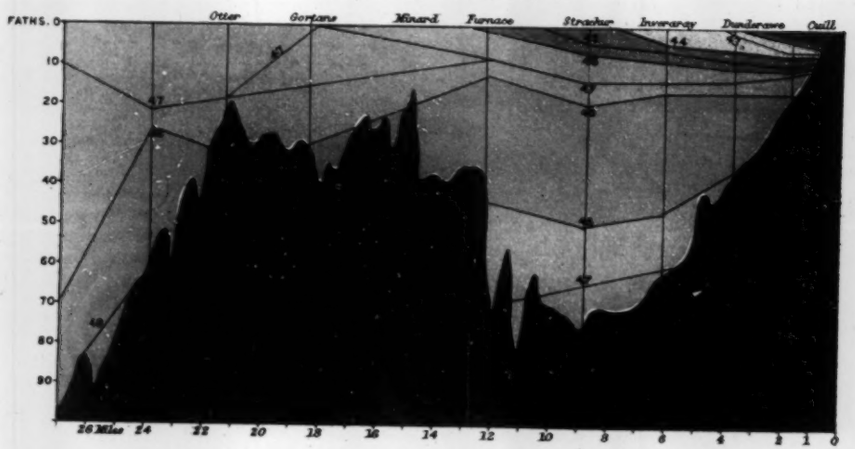
XV 7TH NOVEMBER 1887



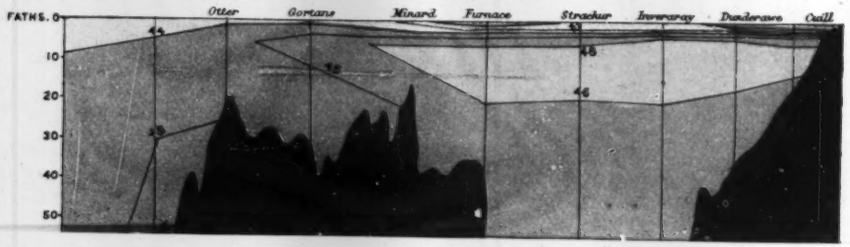
SCALE OF COLOURING FOR TEMPERATURE

above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
under 40°

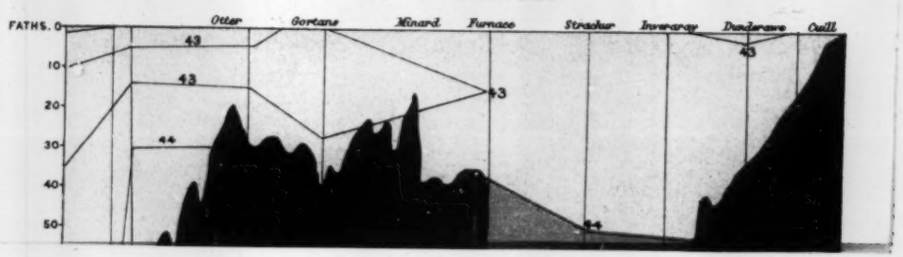
XVI 16TH-17TH DECEMBER 1887

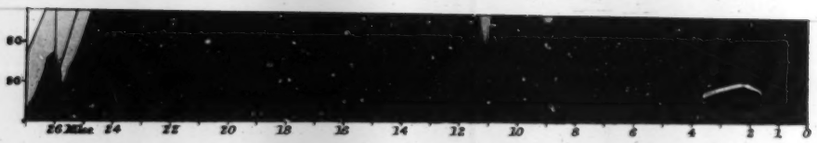


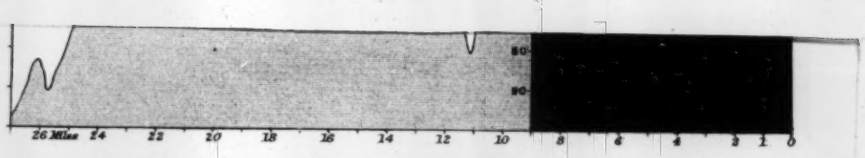
XVII 14TH FEBRUARY 1888



XVIII 22ND-23RD MARCH 1888



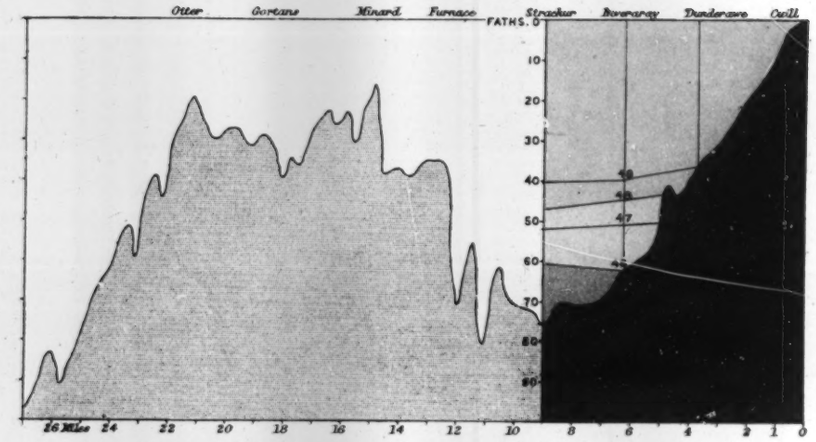




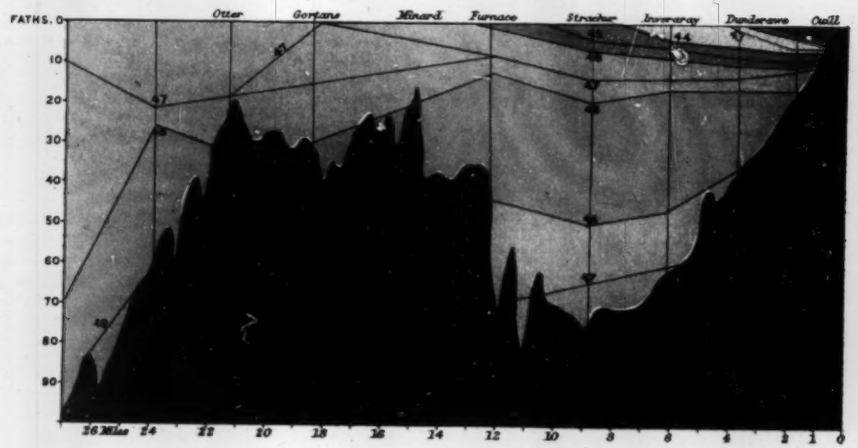
Scale of Colouring for Temperature

above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
below 40°

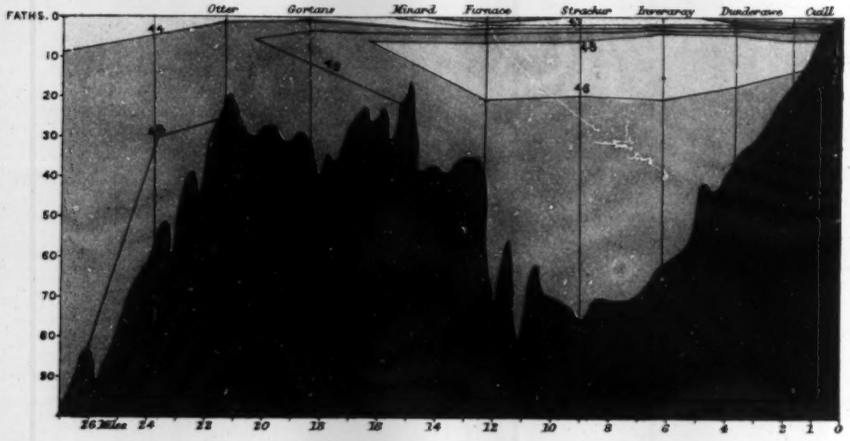
XV 7TH NOVEMBER 1887



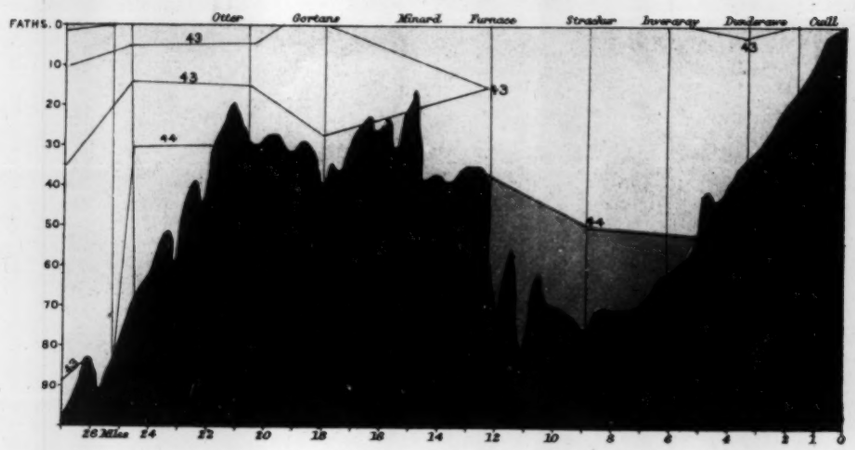
XVI 16TH-17TH DECEMBER 1887



XVII 14TH FEBRUARY 1888



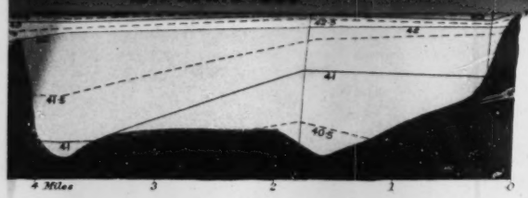
XVIII 22ND-23RD MARCH 1888



Bartholomew Edinr

TEMPERATURE SECTIONS OF LOCH FYNE

TEMPERATURE SECTIONS OF GARELOCH



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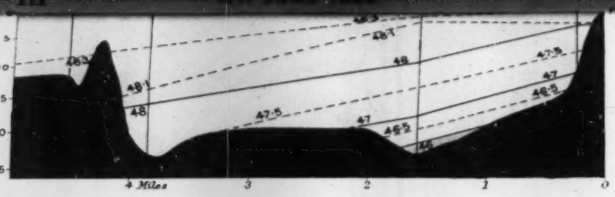

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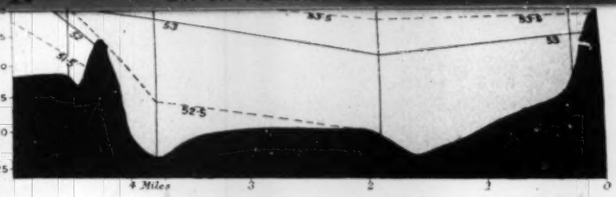
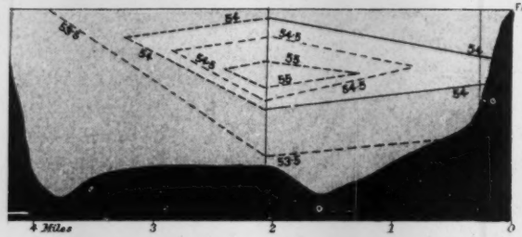
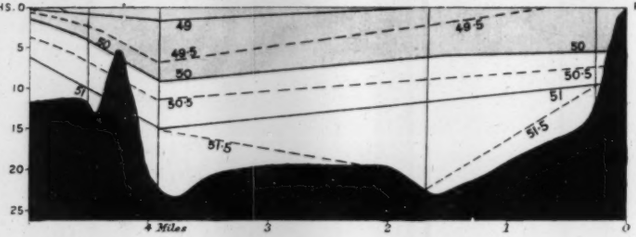


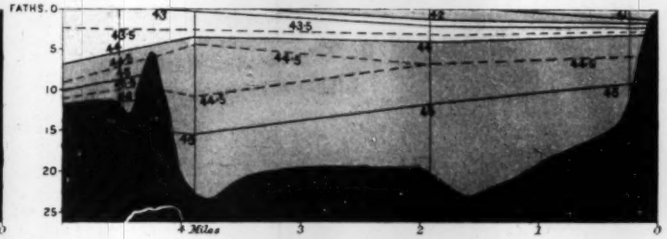
24TH SEPTEMBER 1886



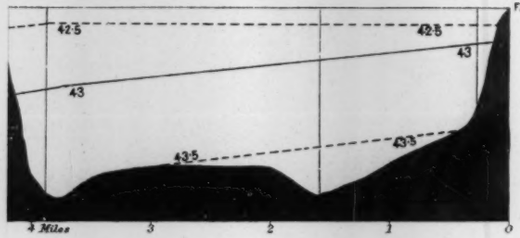
VI 11TH NOVEMBER 1886



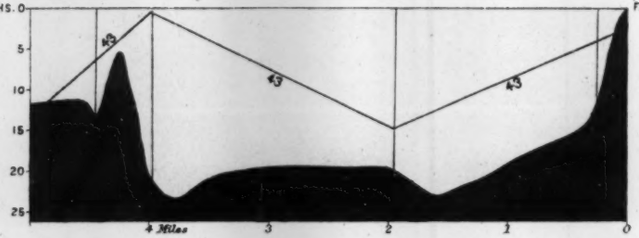
VII 28TH DECEMBER 1886



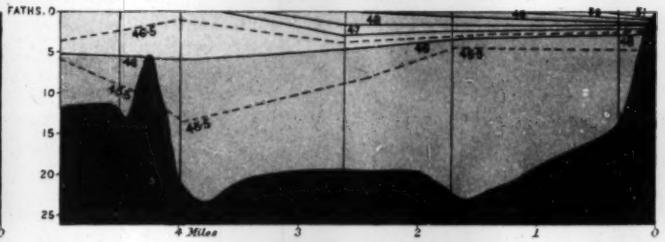
12TH FEBRUARY 1887



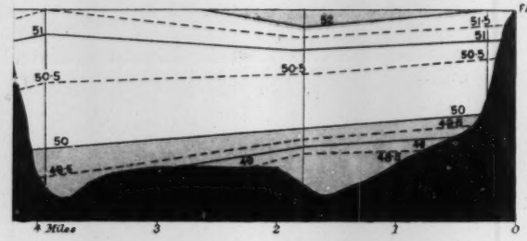
IX 25TH MARCH 1887



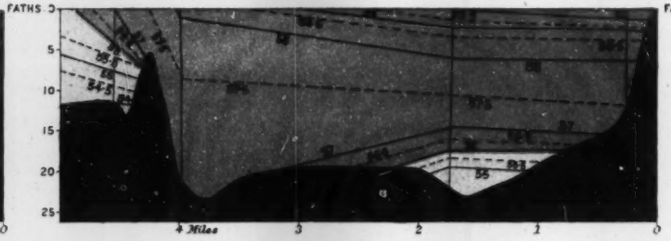
X 6TH MAY 1887



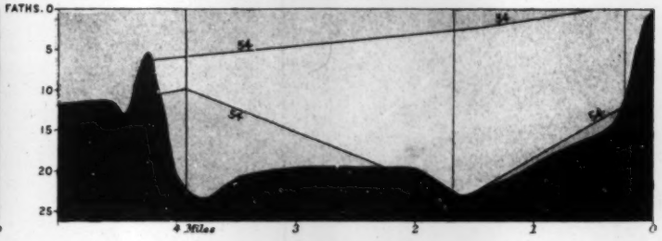
13TH JUNE 1887



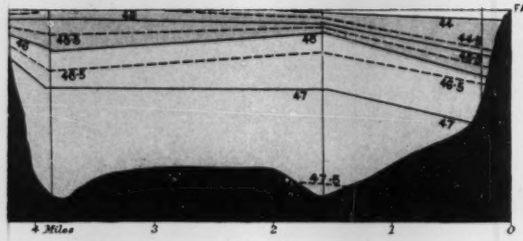
XII 6TH AUGUST 1887



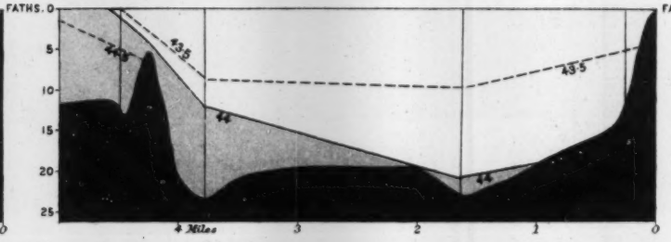
XIII 30TH SEPTEMBER 1887



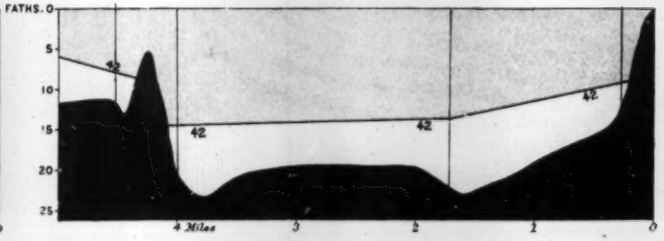
29TH NOVEMBER 1887



XV 9TH FEBRUARY 1888



XVI 28TH MARCH 1888



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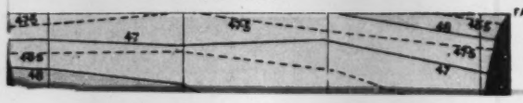
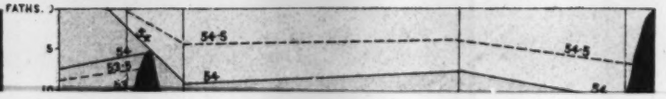
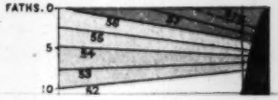


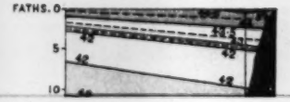
XIX 6TH SEPTEMBER 1888



XVIII 20TH AUGUST 1888



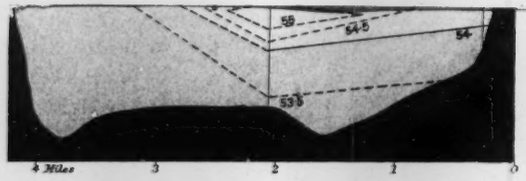
II 21ST APRIL 1886



SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°

TEMPERATURE SECTIONS OF GARELOCH



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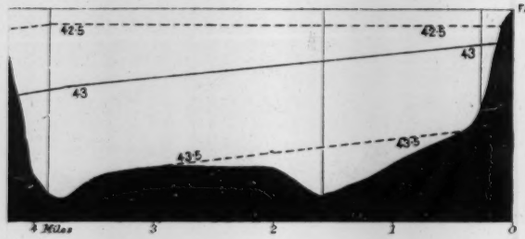
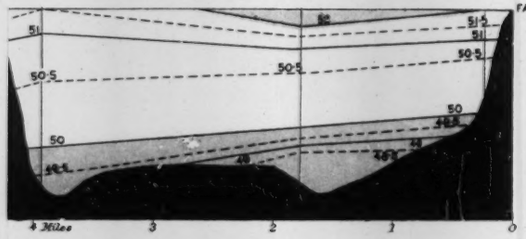


13TH JUNE 1887



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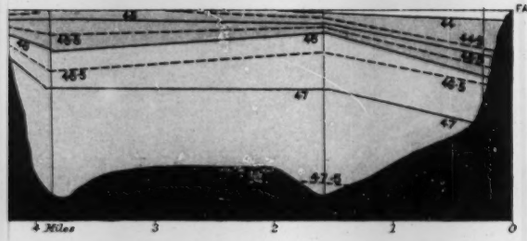

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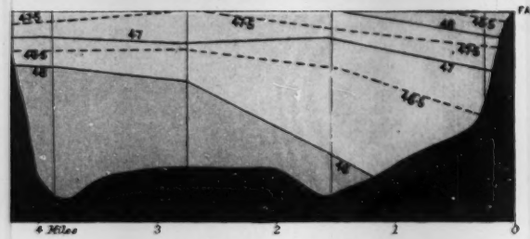
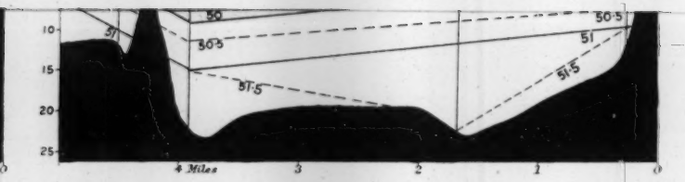
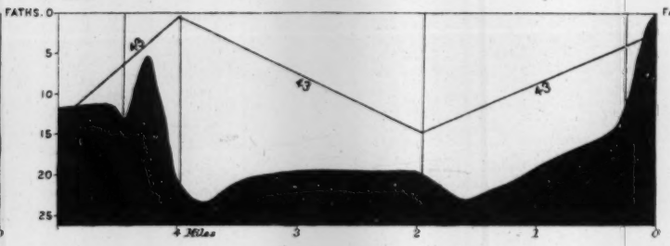
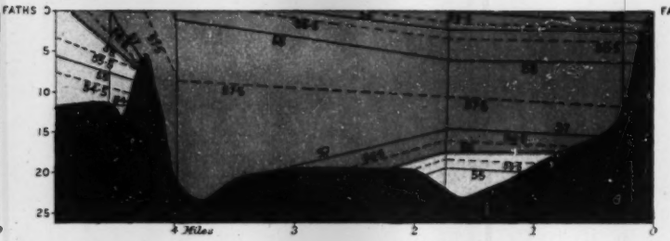


IX 25TH MARCH 1887

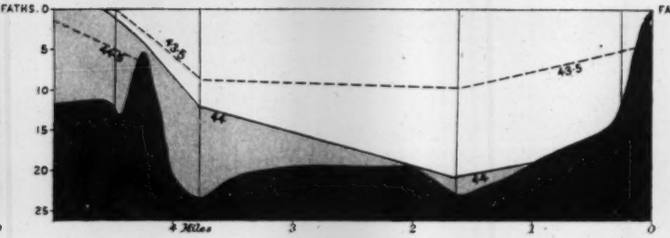




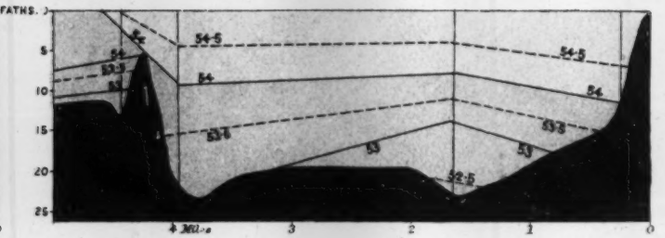
XII 6TH AUGUST 1887



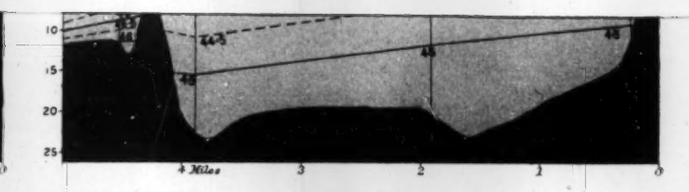
XV 9TH FEBRUARY 1888

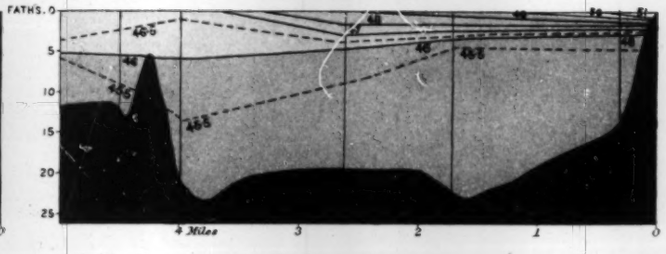


XIX 6TH SEPTEMBER 1888

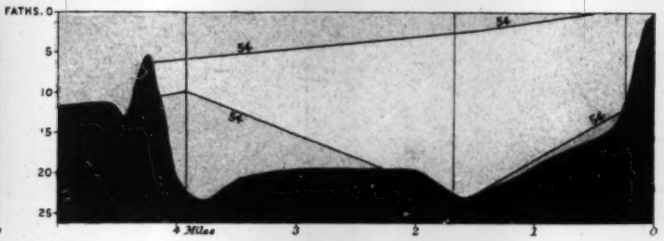


X 6TH MAY 1887

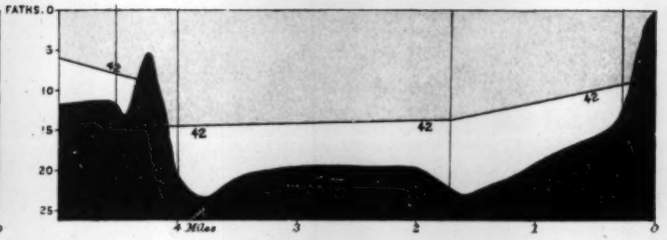




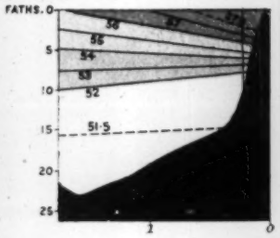
XIII 30TH SEPTEMBER 1887



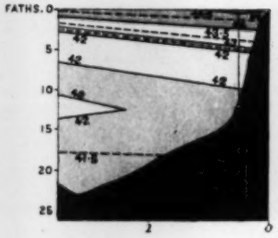
XVI 28TH MARCH 1888



XVIII 20TH AUGUST 1888



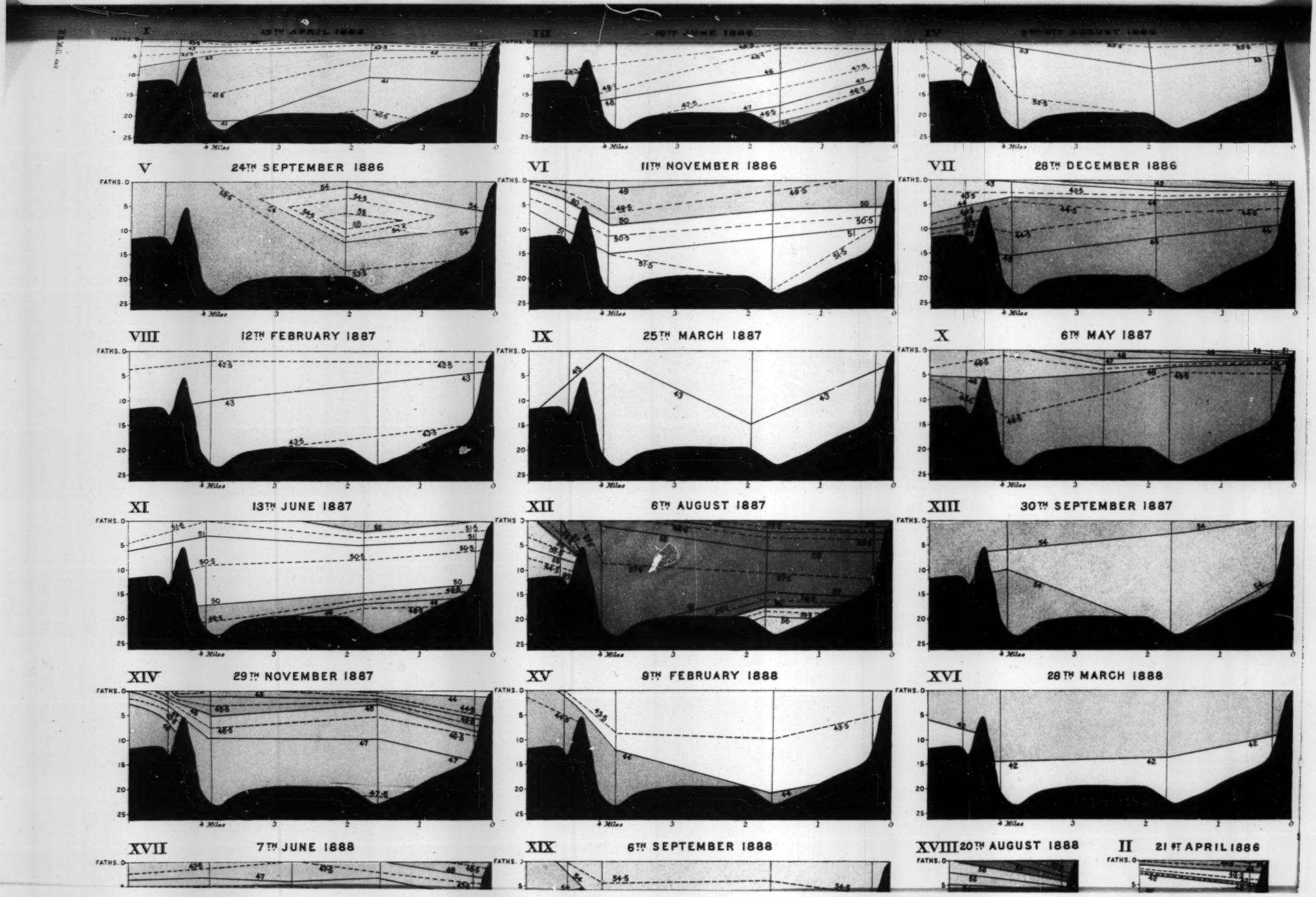
II 21ST APRIL 1886

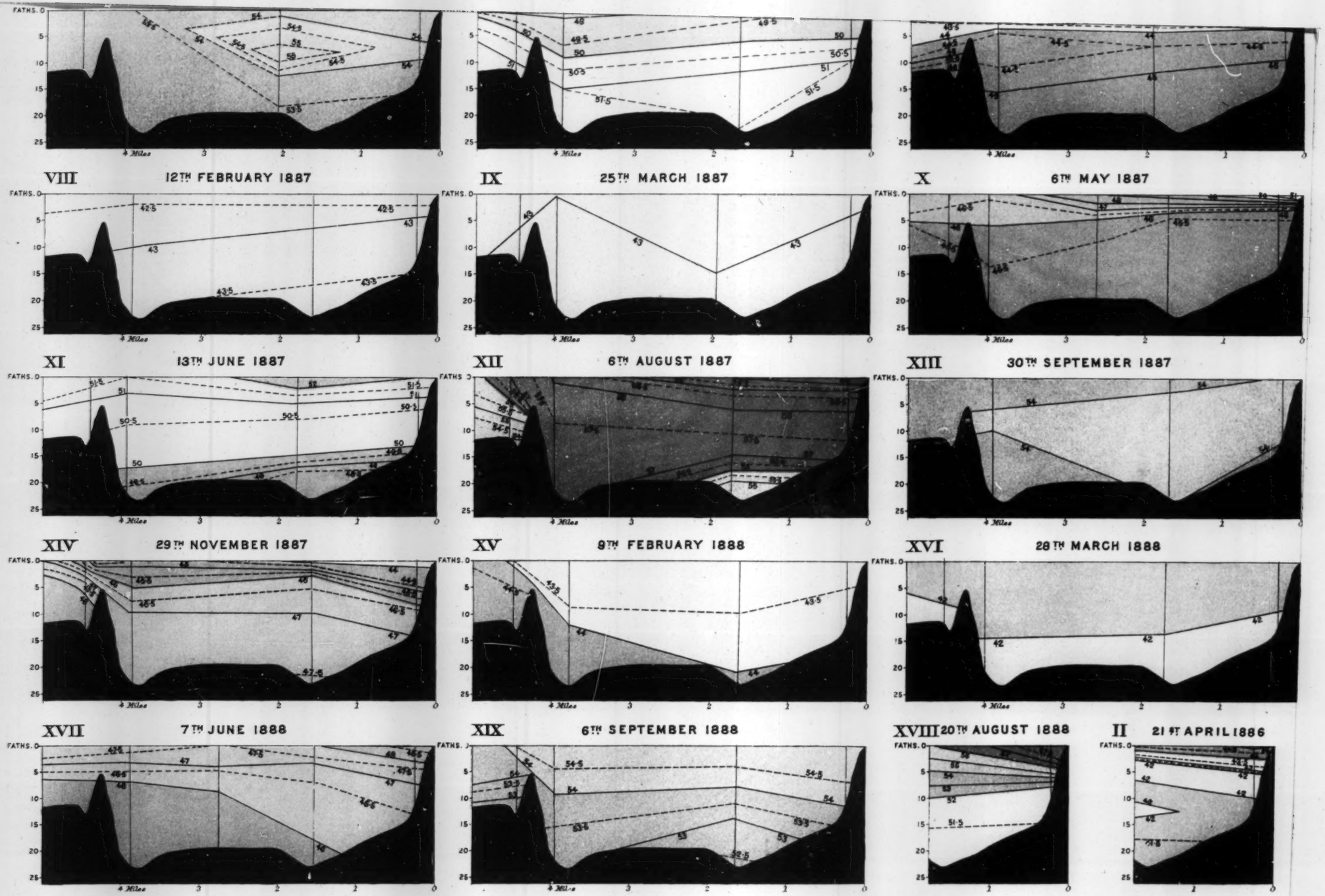


SCALE OF COLOURING FOR TEMPERATURE

ABOVE 56°
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°
40° – 42°
BELOW 40°

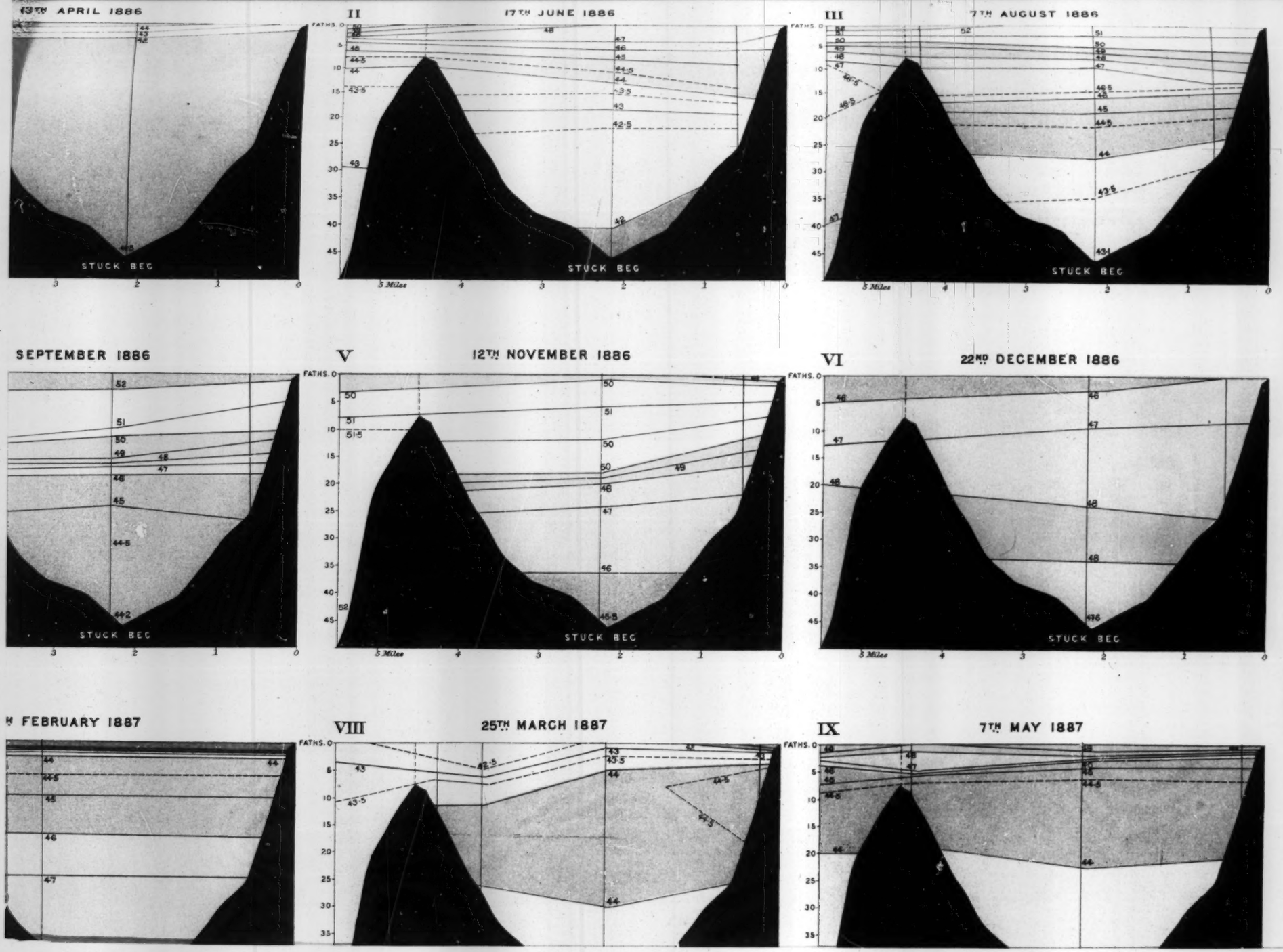
PLATE XVI


I
9TH APRIL 1886
III
III
IV
V
24TH SEPTEMBER 1886
VI
11TH NOVEMBER 1886
VII
28TH DECEMBER 1886
VIII
12TH FEBRUARY 1887
IX
25TH MARCH 1887
X
6TH MAY 1887
XI
13TH JUNE 1887
XII
6TH AUGUST 1887
XIII
30TH SEPTEMBER 1887
XIV
29TH NOVEMBER 1887
XV
9TH FEBRUARY 1888
XVI
28TH MARCH 1888
XVII
7TH JUNE 1888
XIX
6TH SEPTEMBER 1888
XVIII
20TH AUGUST 1888
II
21ST APRIL 1886
FATHS.
Miles



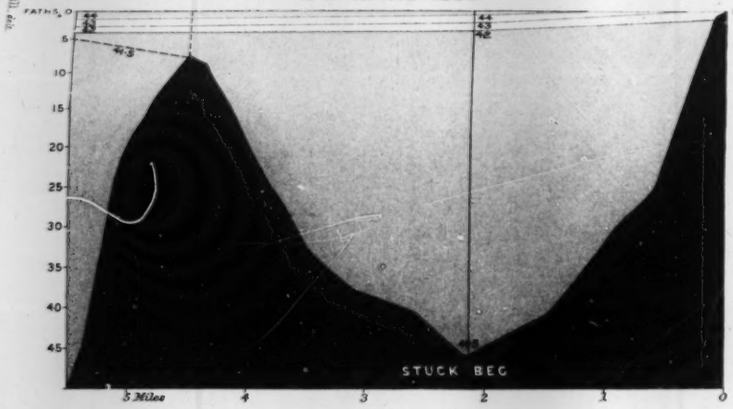
Bartholomew, Edin.r

TEMPERATURE SECTIONS OF LOCH GOIL

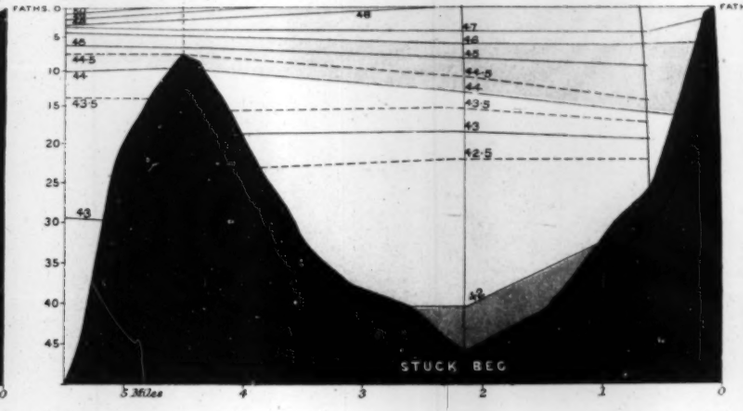


TEMPERATURE SECTIONS OF LOCH GOIL

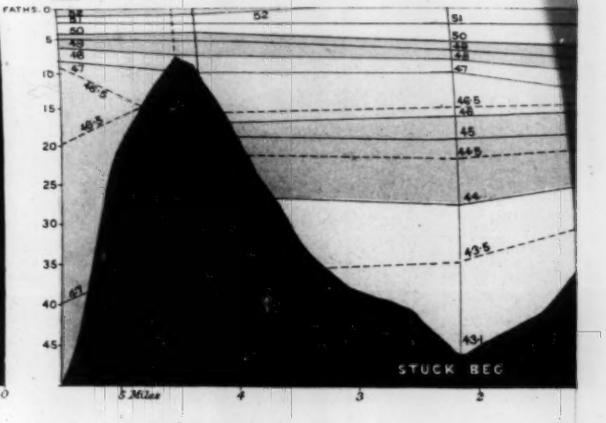
I 13TH APRIL 1886



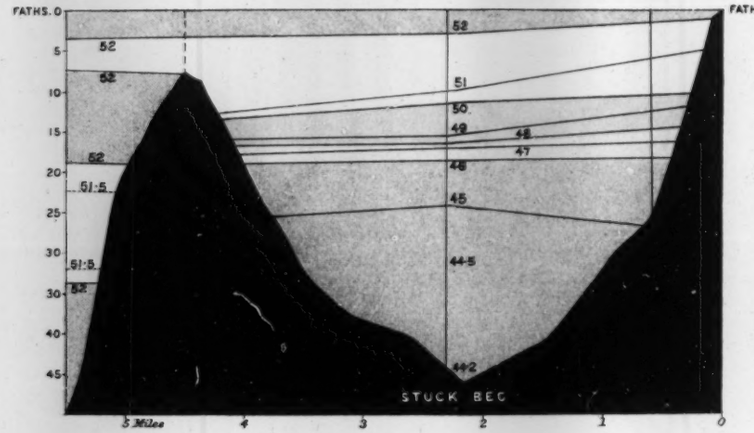
II 17TH JUNE 1886



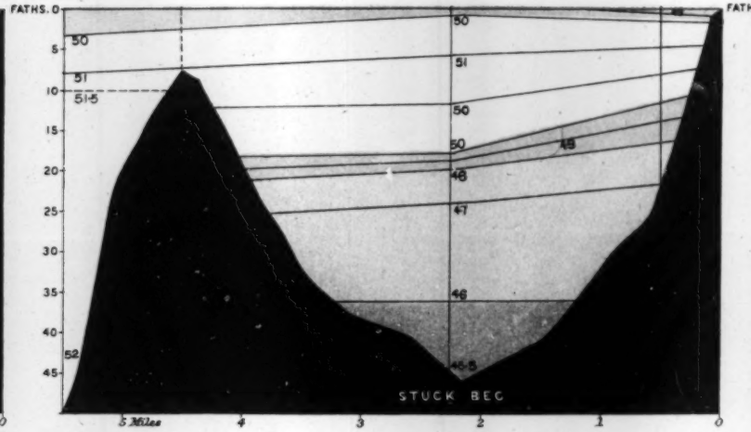
III 7TH AUGUST 1886



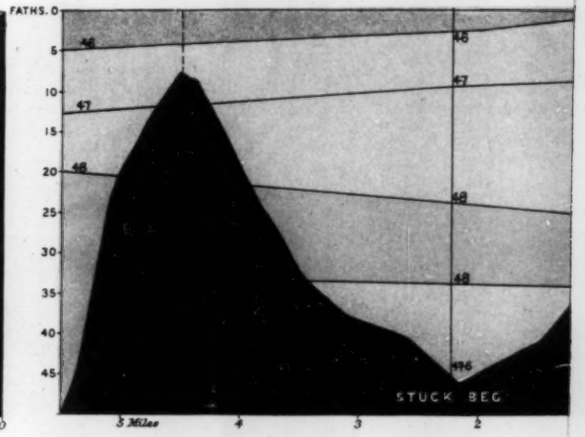
IV 24TH SEPTEMBER 1886



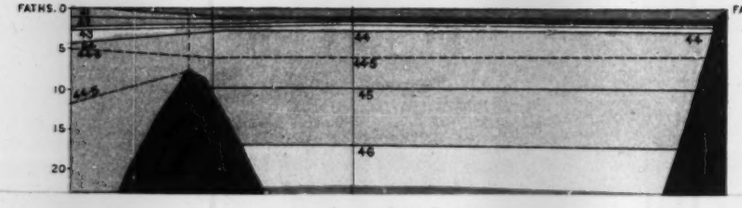
V 12TH NOVEMBER 1886



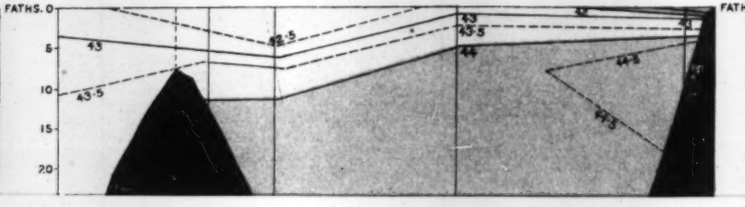
VI 22ND DECEMBER 1886



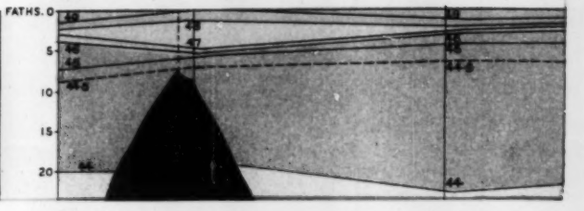
VII 8TH FEBRUARY 1887

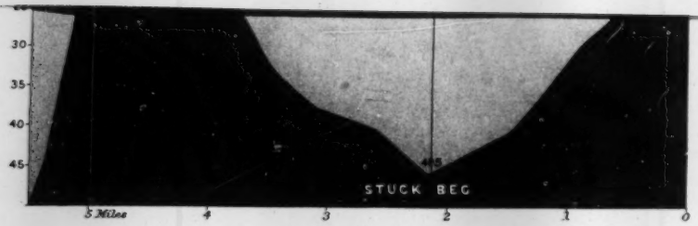


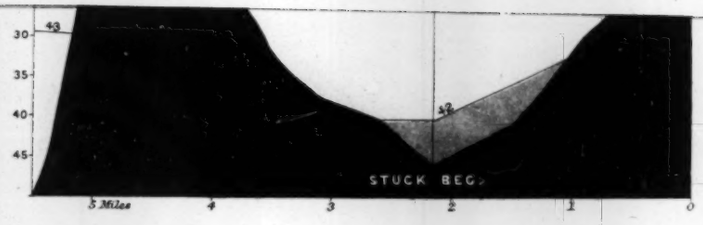
VIII 25TH MARCH 1887

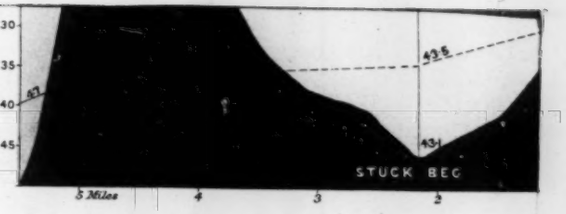


IX 7TH MAY 1887

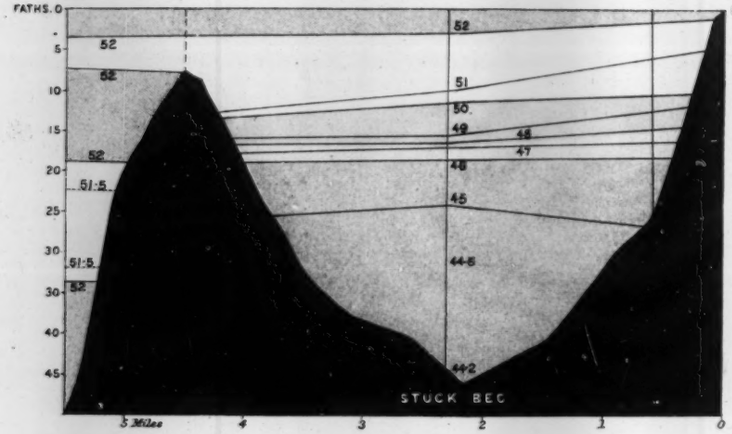




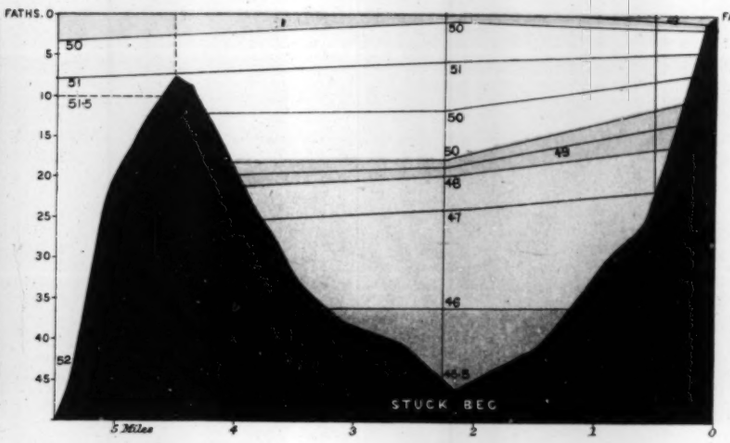




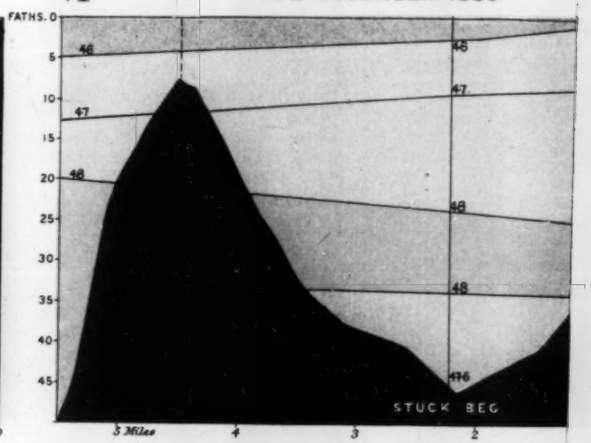
IV 24TH SEPTEMBER 1886



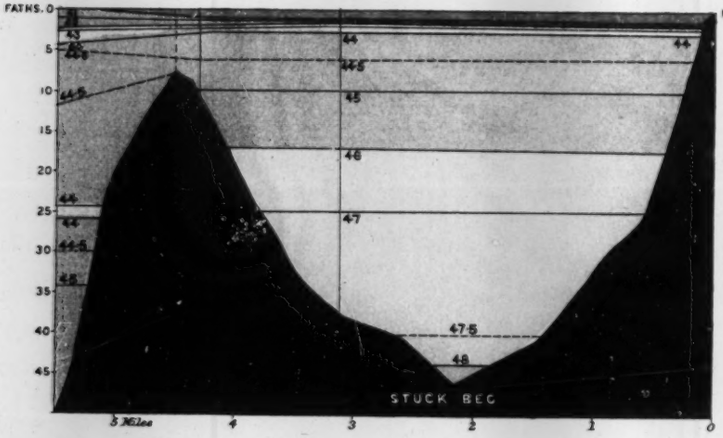
V 12TH NOVEMBER 1886



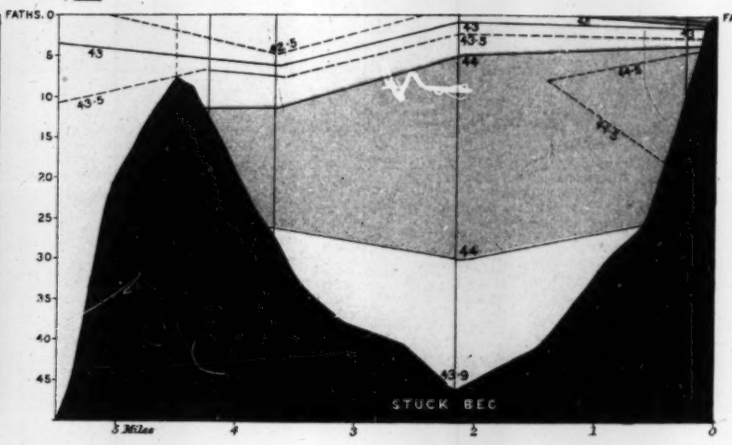
VI 22ND DECEMBER 1886



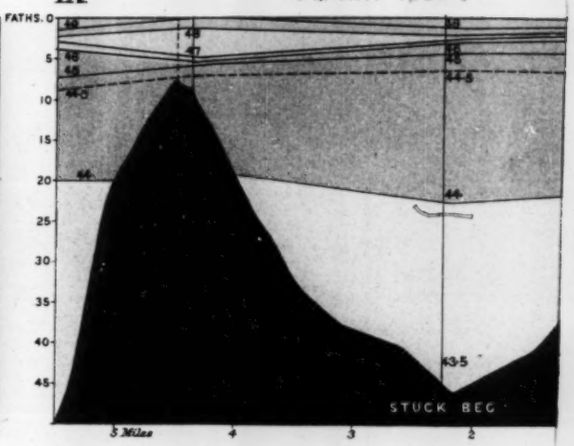
VII 8TH FEBRUARY 1887



VIII 25TH MARCH 1887



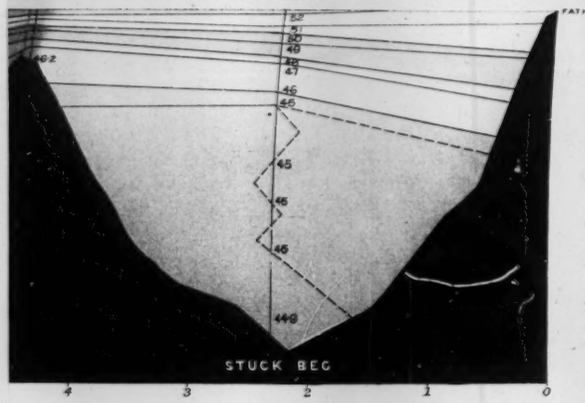
IX 7TH MAY 1887



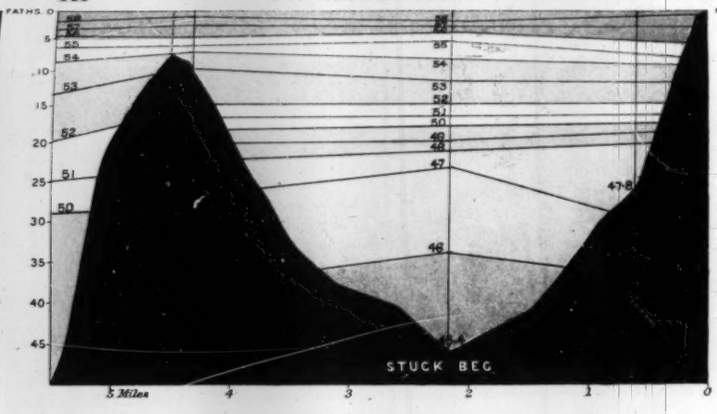
Bartholomew, Edin.

TEMPERATURE SECTIONS OF LOCH GOIL

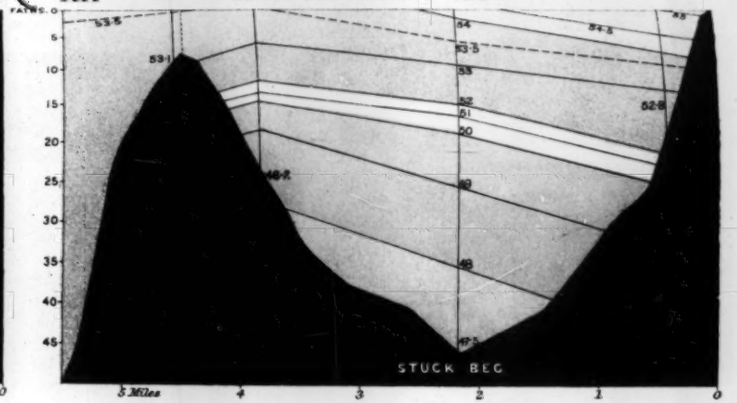
14TH JUNE 1887



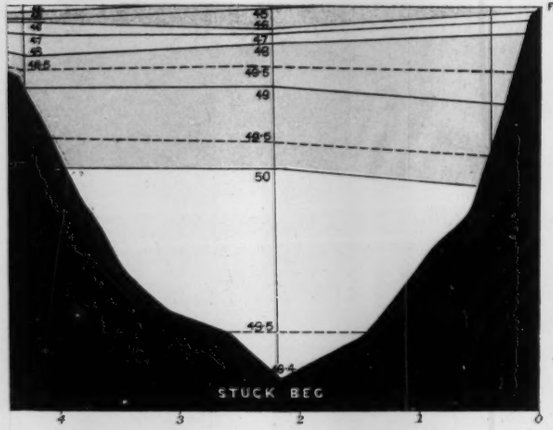
XI 7TH AUGUST 1887



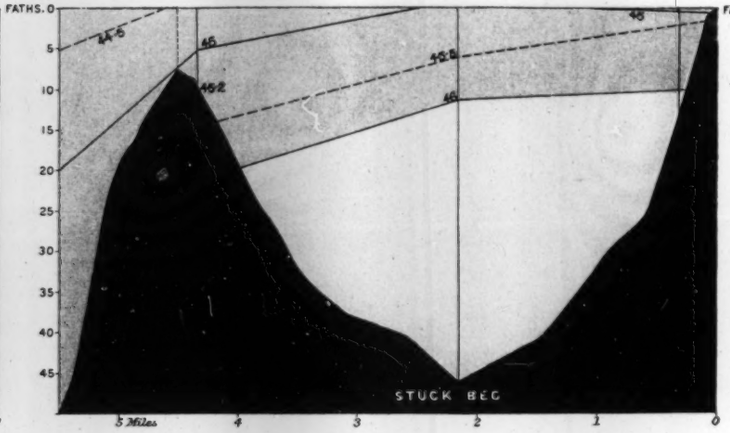
XII 29TH SEPTEMBER 1887



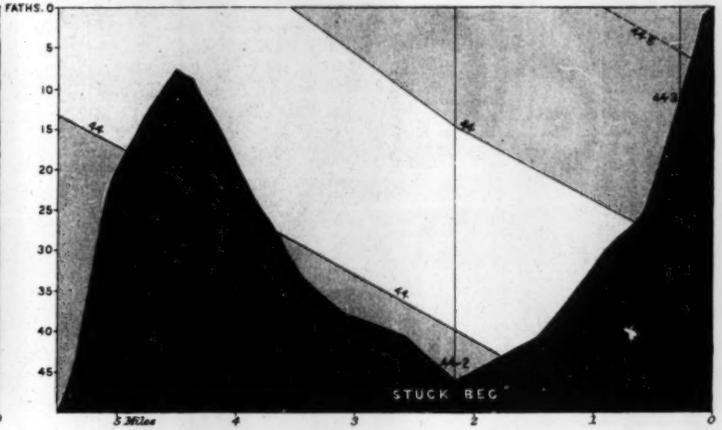
30TH NOVEMBER 1887



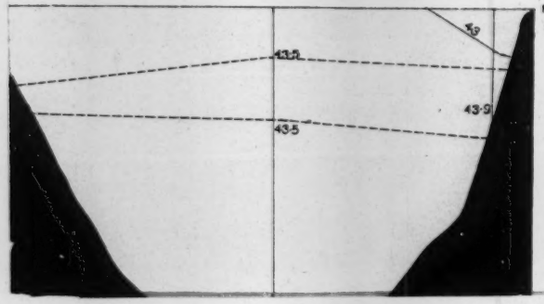
XIV 9TH-10TH FEBRUARY 1888



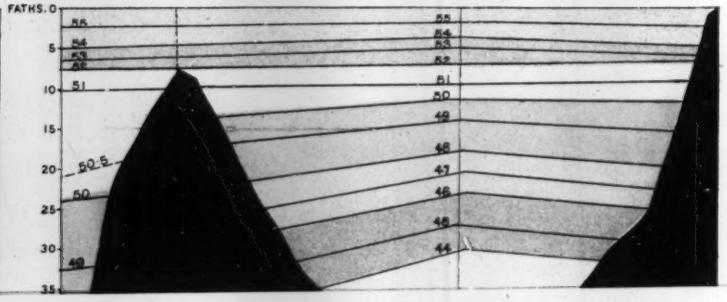
XV 1ST MARCH 1888



28TH MARCH 1888

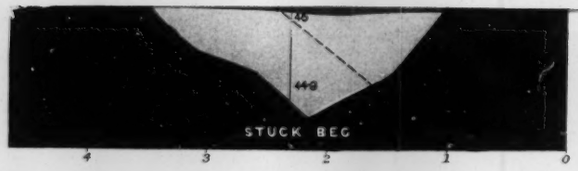


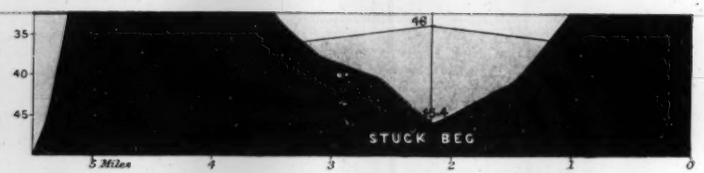
XVII 3RD SEPTEMBER 1888



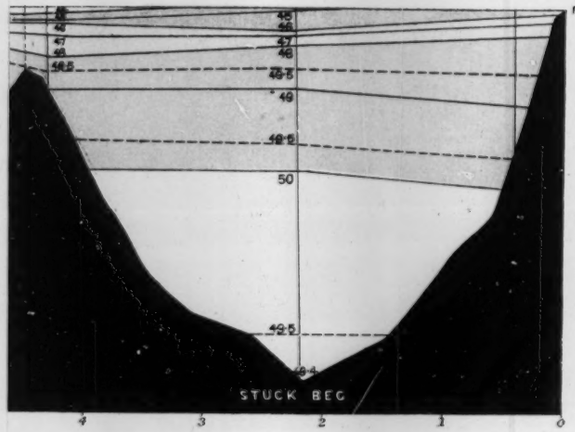
SCALE OF COLOURING FOR TEMPERATURE

above 56°
54° to 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°

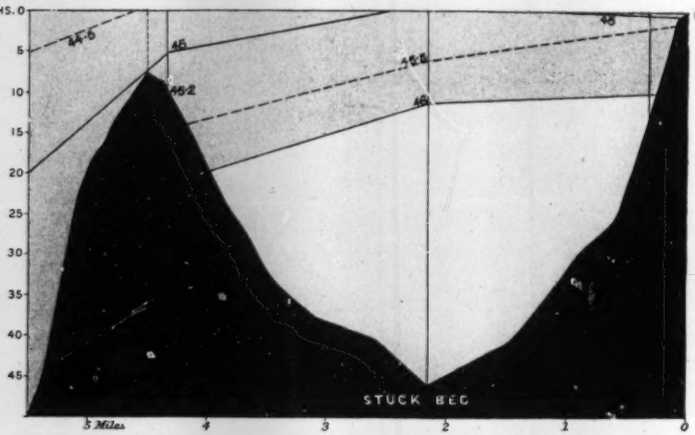




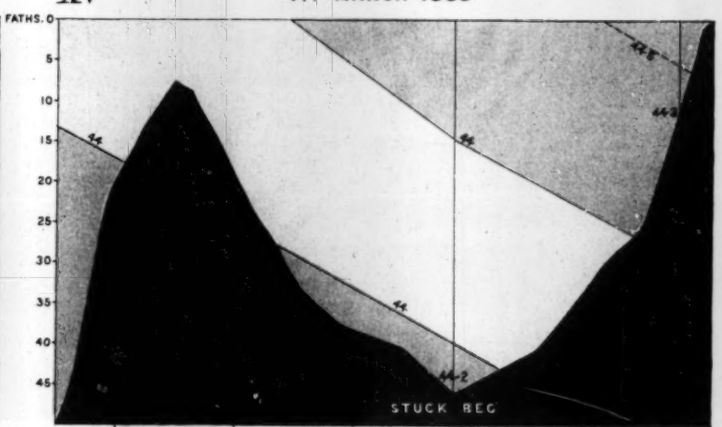
30TH NOVEMBER 1887



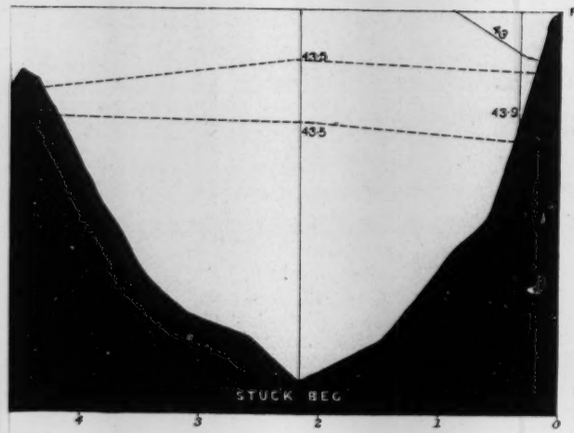
XIV 9TH-10TH FEBRUARY 1888



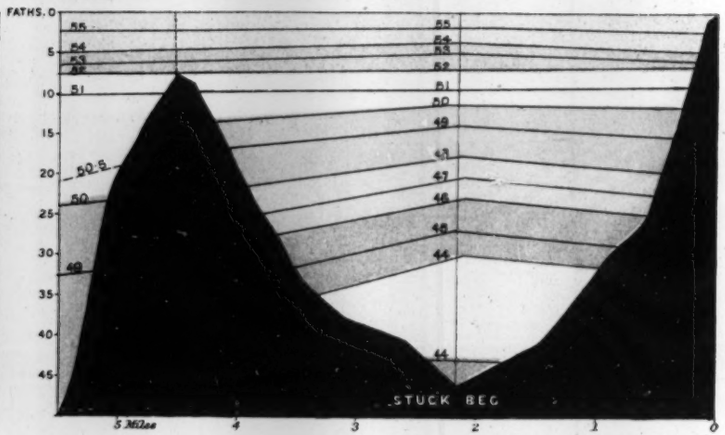
XV 1ST MARCH 1888



28TH MARCH 1888



XVII 3RD SEPTEMBER 1888



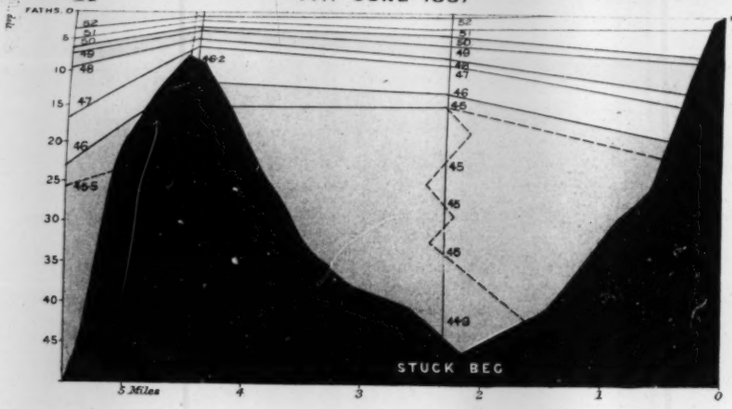
SCALE OF COLOURING FOR TEMPERATURE

56°
54° to 56°
52° - 54°
50° - 52°
48° - 50°
46° - 48°
44° - 46°
42° - 44°
40° - 42°
below 40°

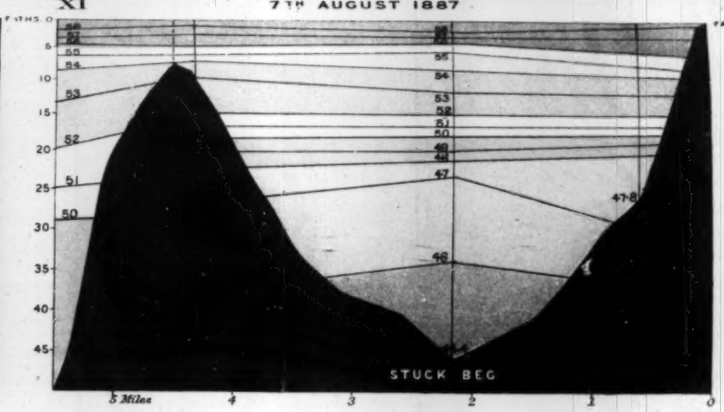
III TEMPERATURE SECTIONS OF LOCH GOIL

PLATE XVIII

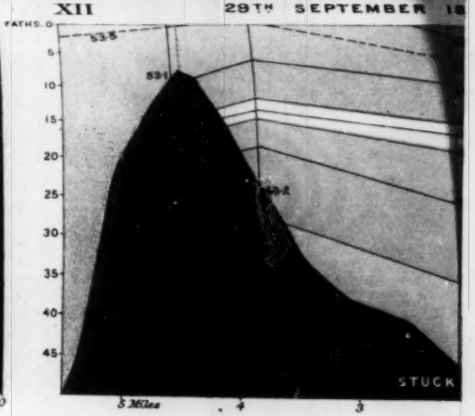
X 14TH JUNE 1887



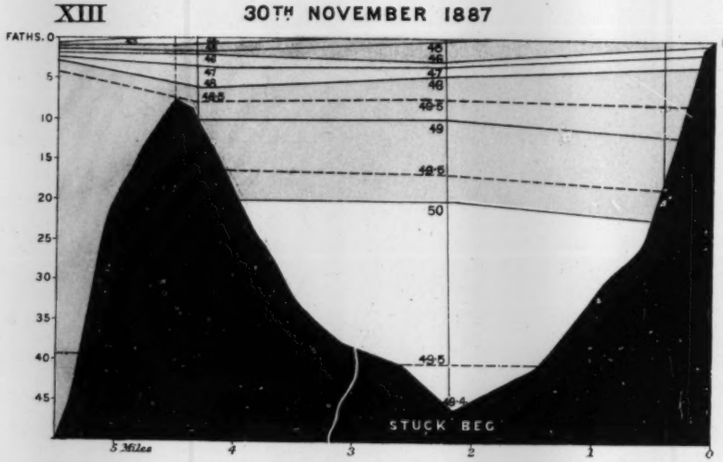
XI 7TH AUGUST 1887



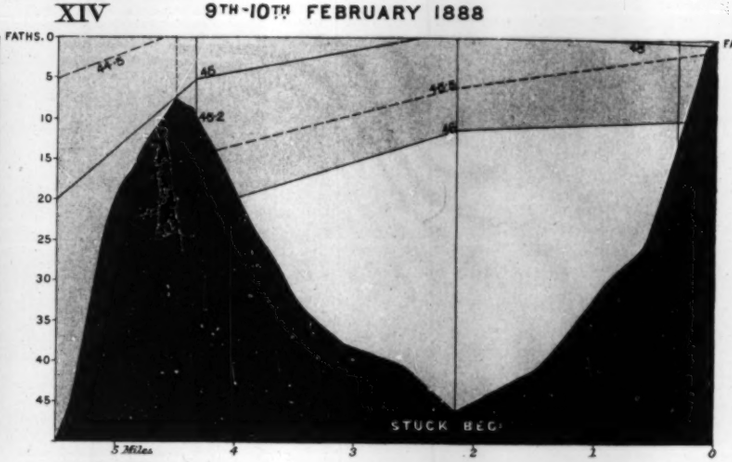
XII 29TH SEPTEMBER 18



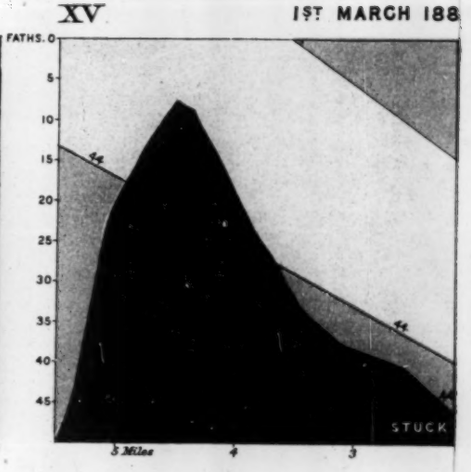
XIII 30TH NOVEMBER 1887



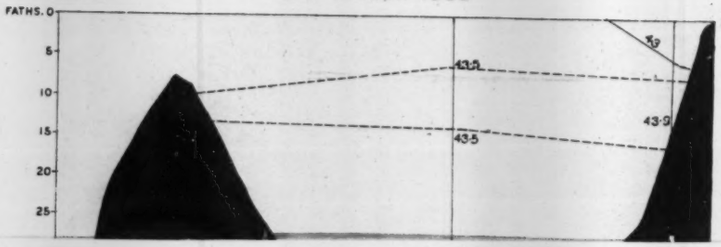
XIV 9TH-10TH FEBRUARY 1888



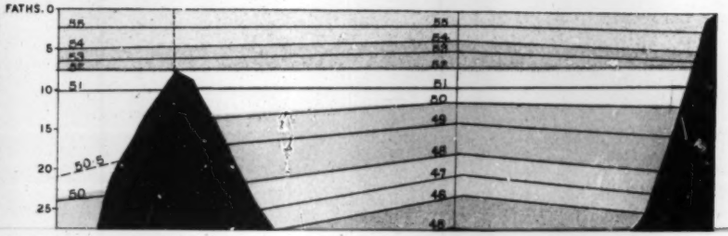
XV 1ST MARCH 188



XVI 28TH MARCH 1888

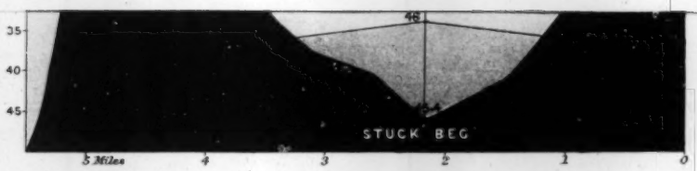


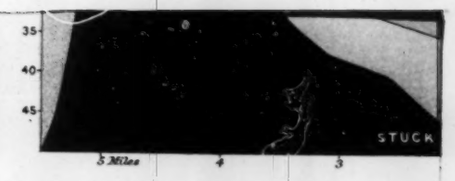
XVII 3RD SEPTEMBER 1888



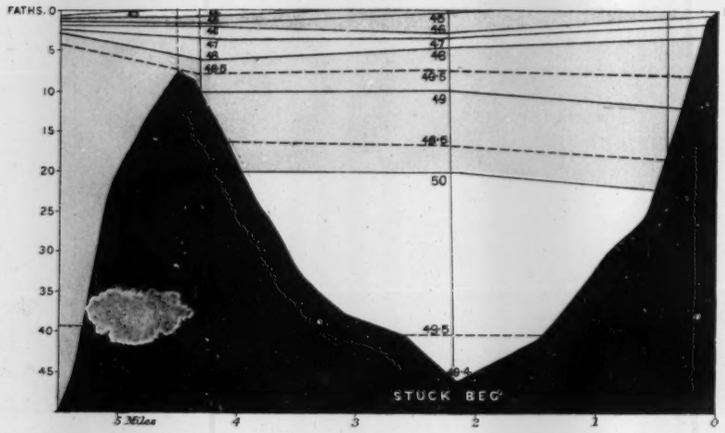
SCALE OF COLOURING FOR TEMPERATURE

54° TO 56°
52° – 54°
50° – 52°
48° – 50°

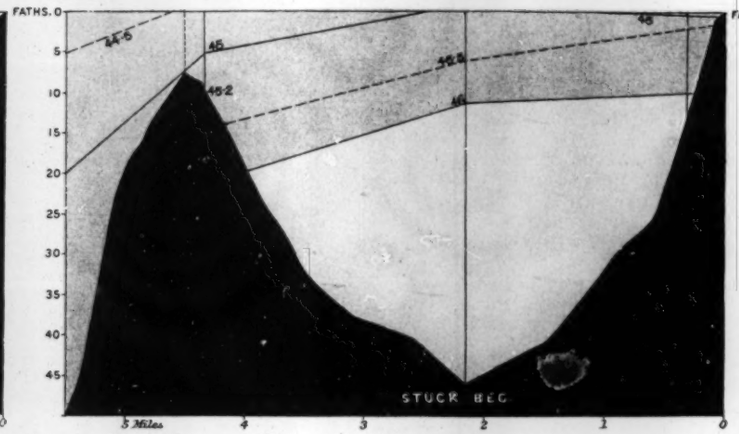




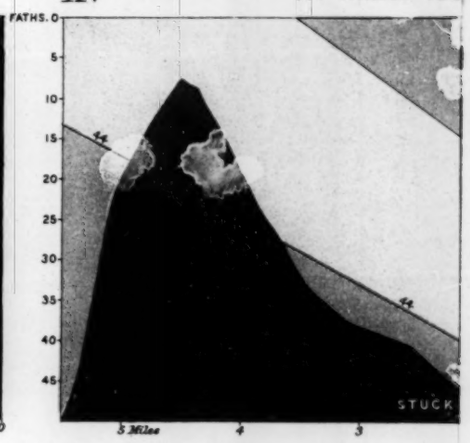
XIII 30TH NOVEMBER 1887



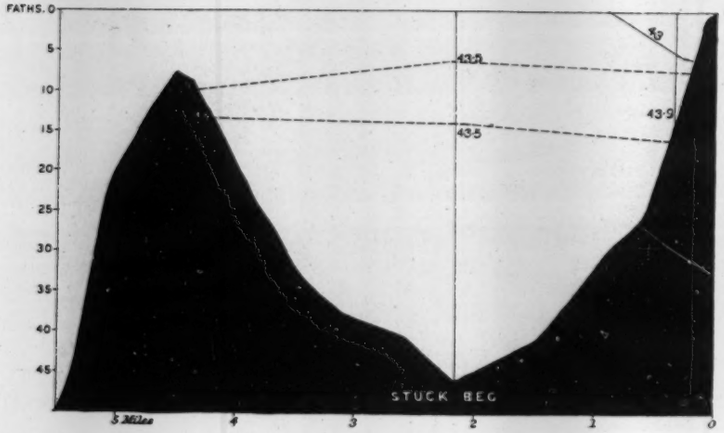
XIV 9TH-10TH FEBRUARY 1888



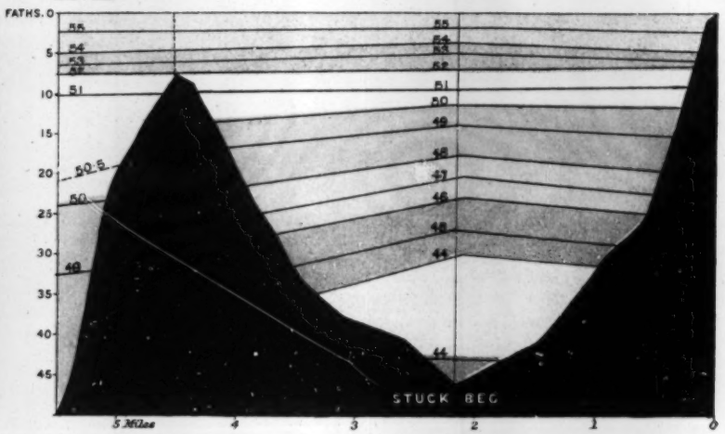
XV 1ST MARCH 188

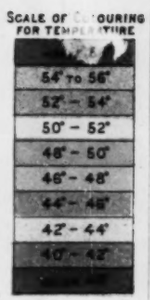


XVI 28TH MARCH 1888



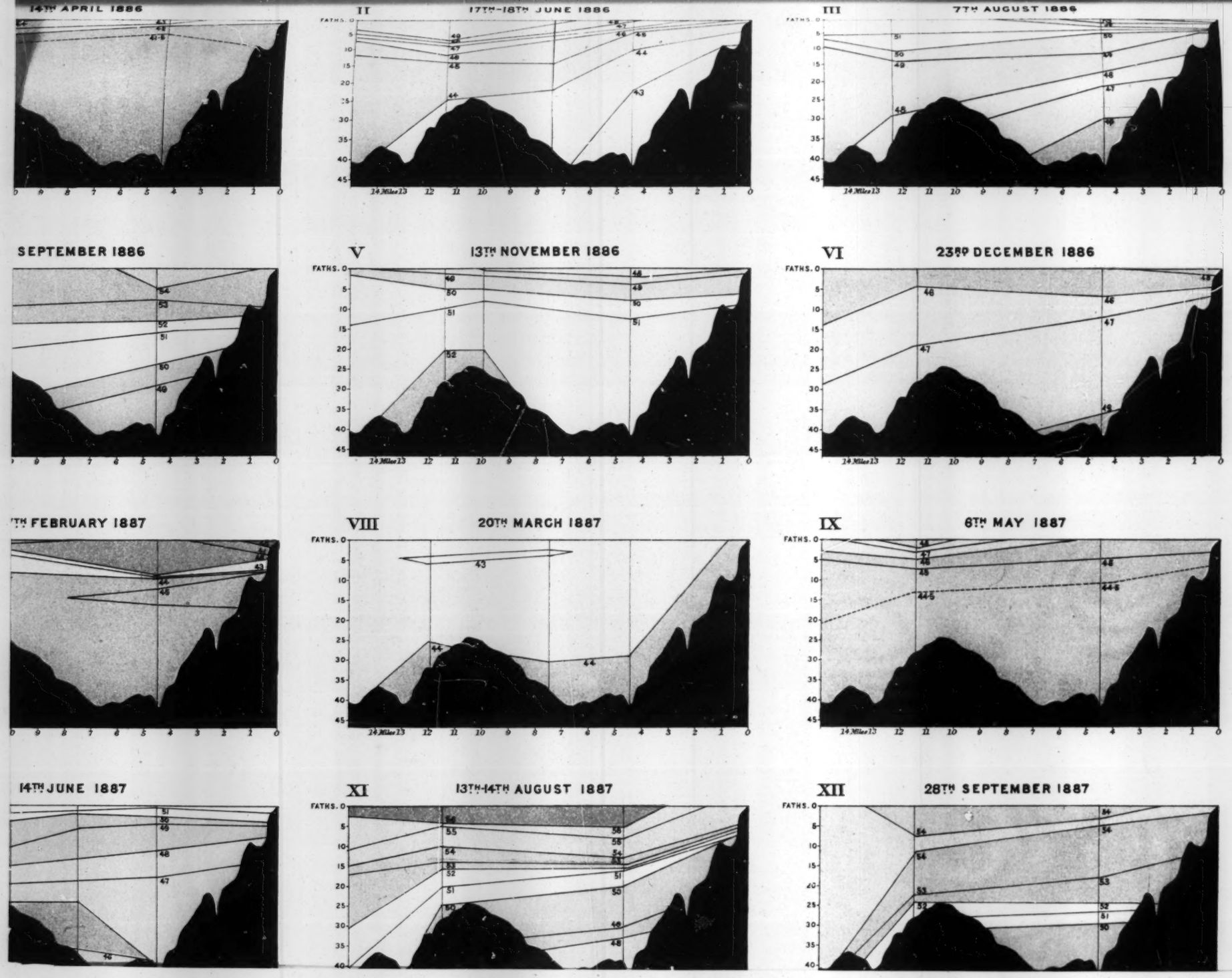
XVII 3RD SEPTEMBER 1888



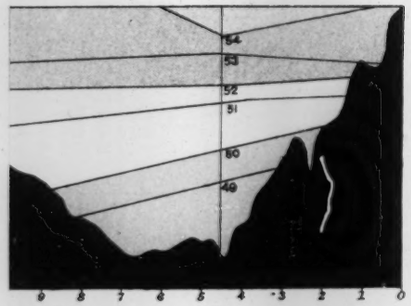


Bartholomew Edin.

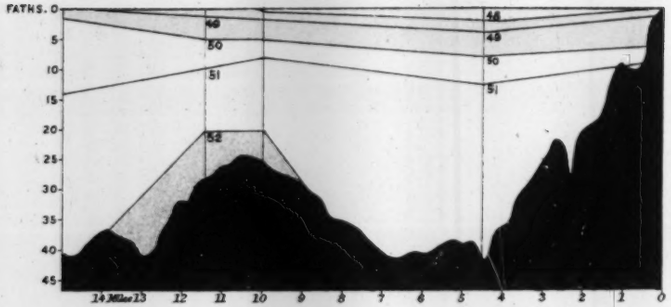
TEMPERATURE SECTIONS OF LOCH STRIVAN



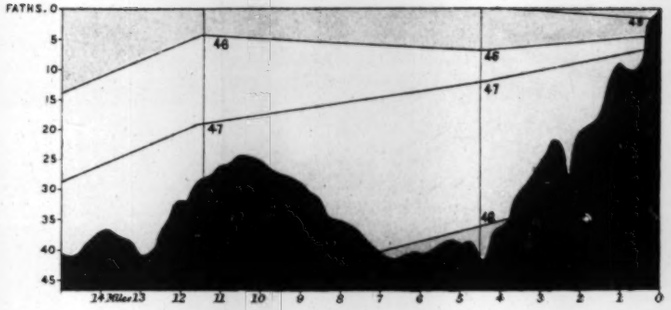
SEPTEMBER 1886



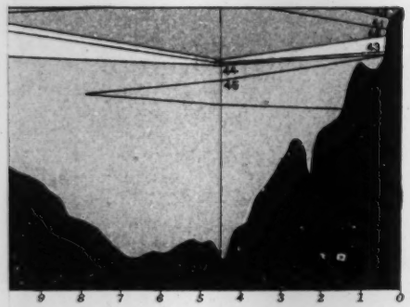
V 13TH NOVEMBER 1886



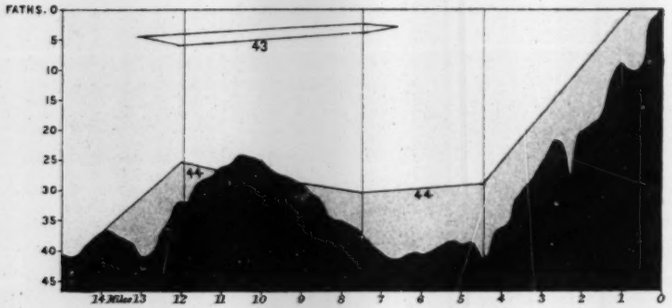
VI 23RD DECEMBER 1886



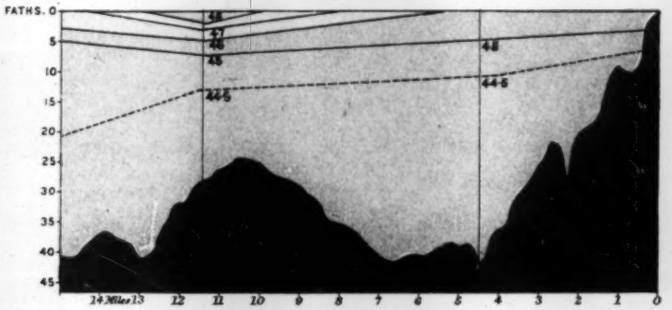
TH FEBRUARY 1887



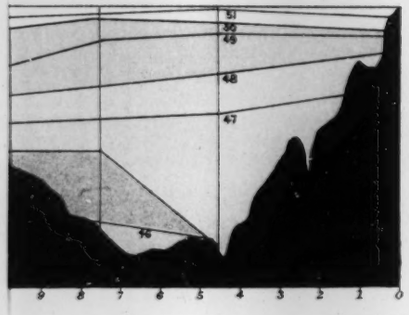
VIII 20TH MARCH 1887



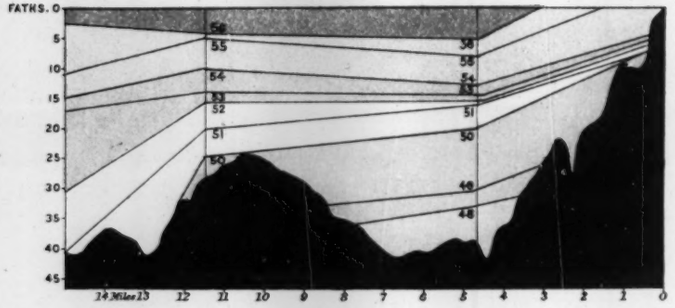
IX 6TH MAY 1887



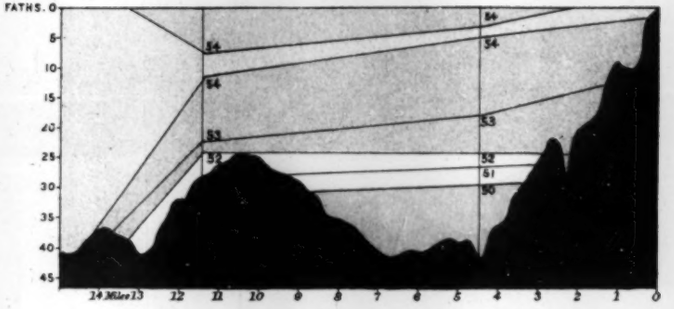
14TH JUNE 1887



XI 13TH-14TH AUGUST 1887



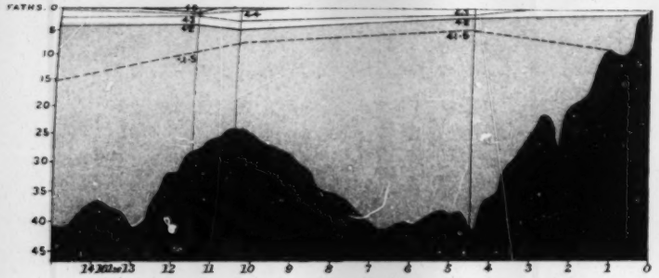
XII 28TH SEPTEMBER 1887



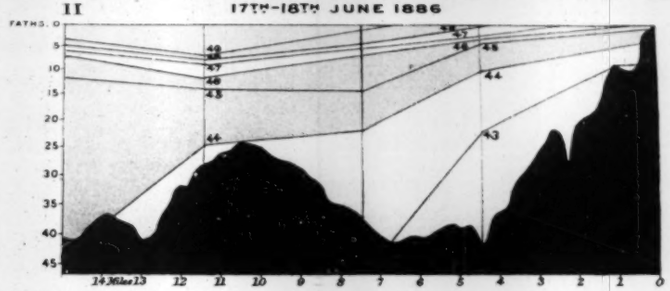
TEMPERATURE SECTIONS OF LOCH STRIVAN

PLATE XIX

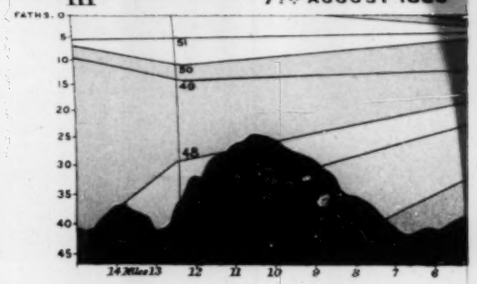
I 14TH APRIL 1886



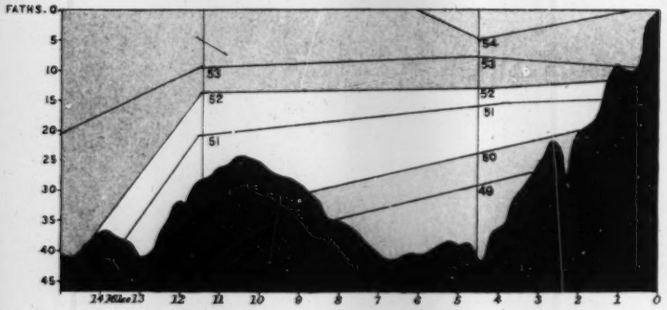
II 17TH-18TH JUNE 1886



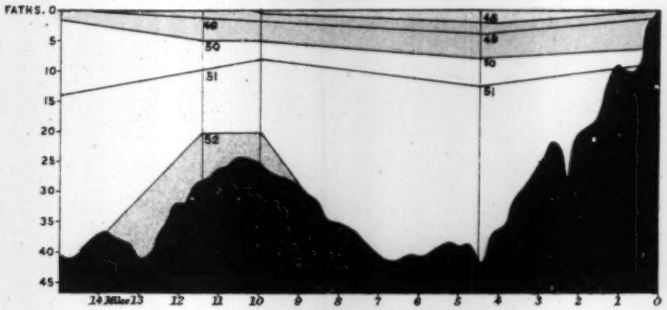
III 7TH AUGUST 1886



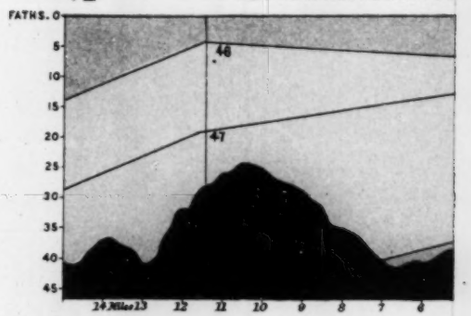
IV 25TH SEPTEMBER 1886



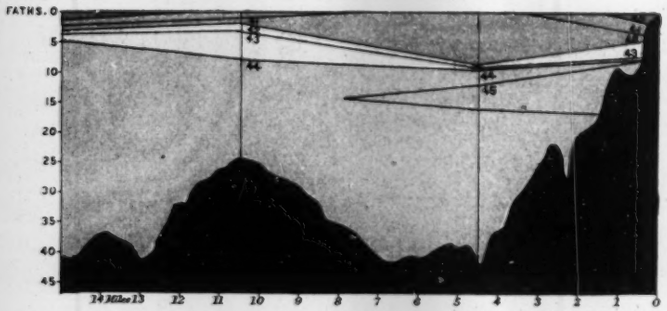
V 13TH NOVEMBER 1886



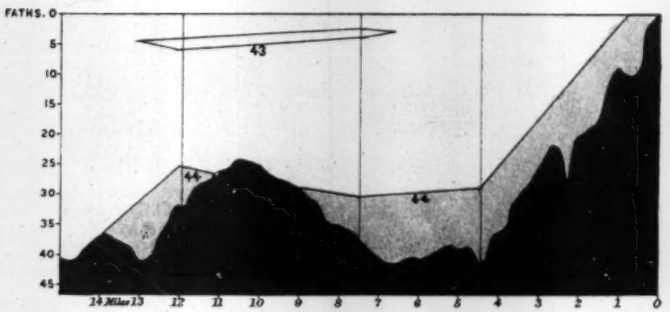
VI 23RD DECEMBER 188



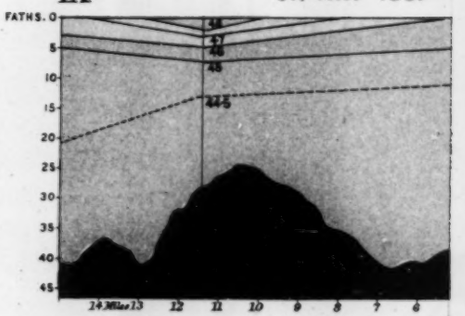
VII 7TH FEBRUARY 1887



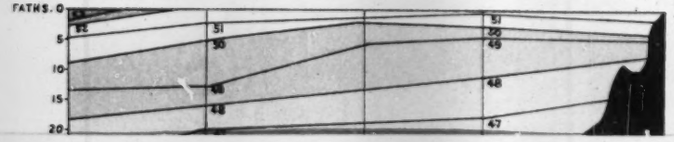
VIII 20TH MARCH 1887



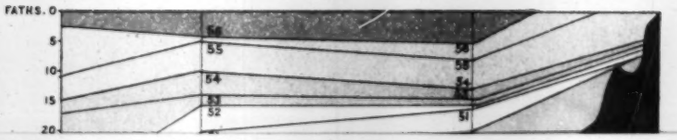
IX 6TH MAY 1887



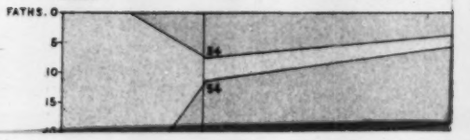
X 14TH JUNE 1887

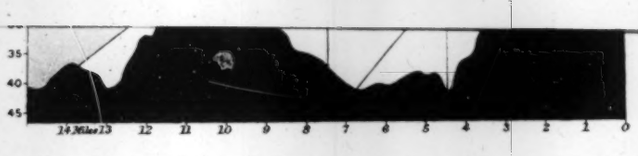


XI 13TH-14TH AUGUST 1887

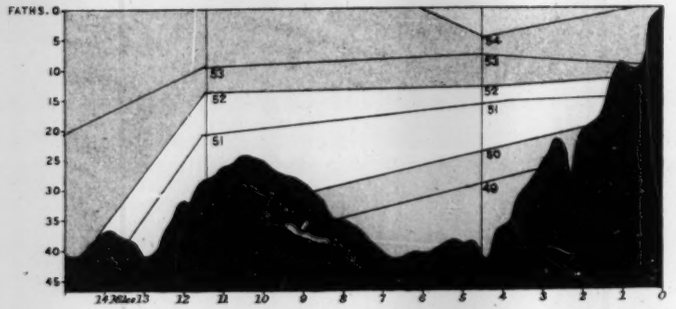


XII 28TH SEPTEMBER 188

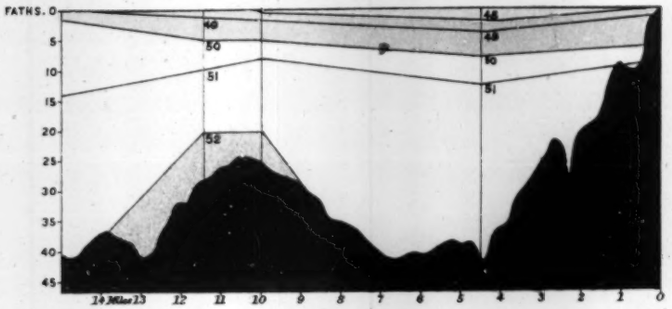




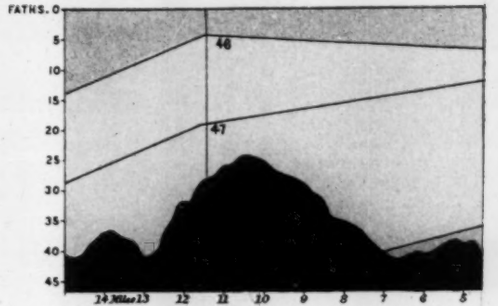
IV 25TH SEPTEMBER 1886



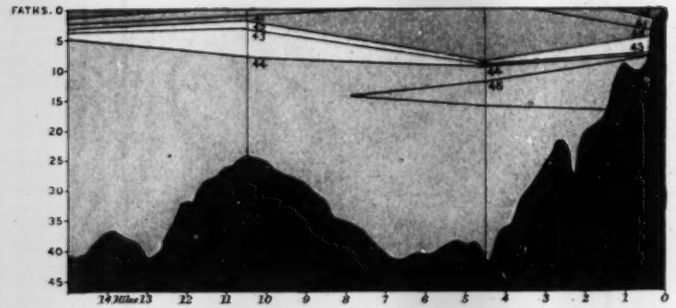
V 13TH NOVEMBER 1886



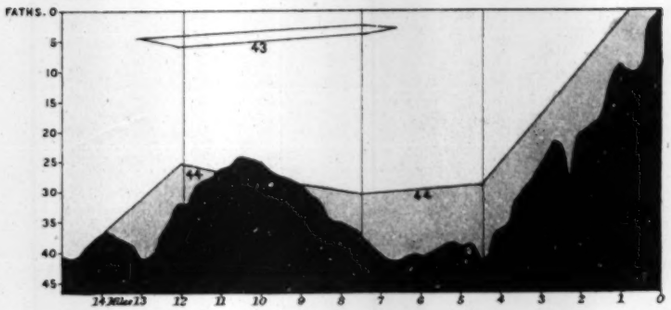
VI 23RD DECEMBER 1886



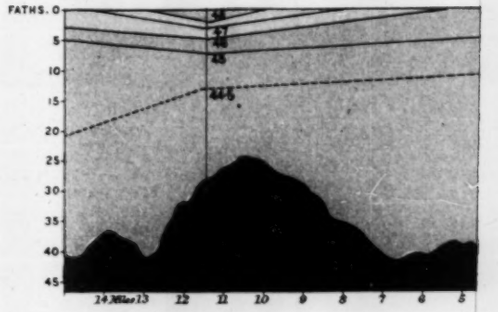
VII 7TH FEBRUARY 1887



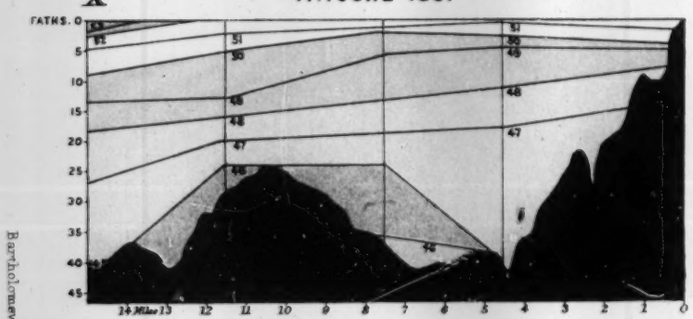
VIII 20TH MARCH 1887



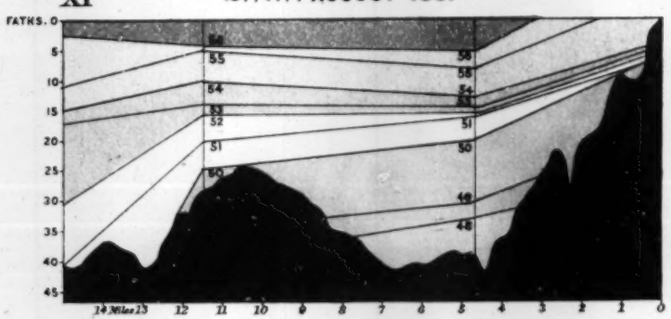
IX 6TH MAY 1887



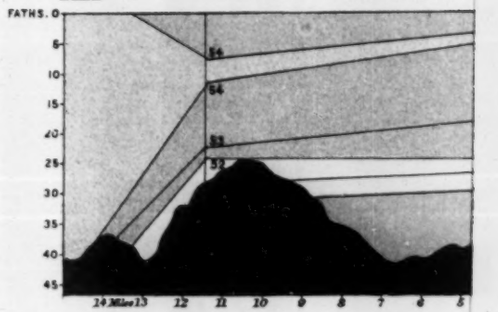
X 14TH JUNE 1887



XI 13TH-14TH AUGUST 1887



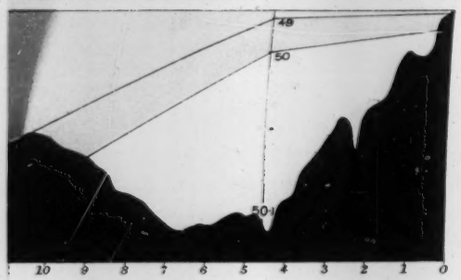
XII 28TH SEPTEMBER 1887



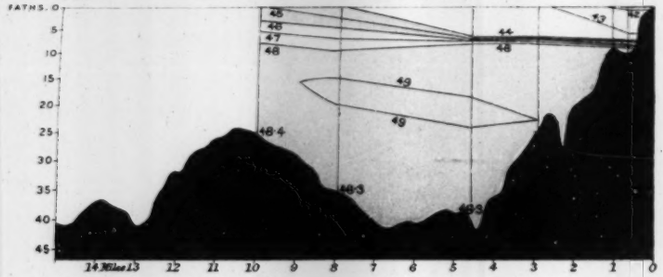
Bartholomew, Edin.

TEMPERATURE SECTIONS OF LOCH STRIVAN

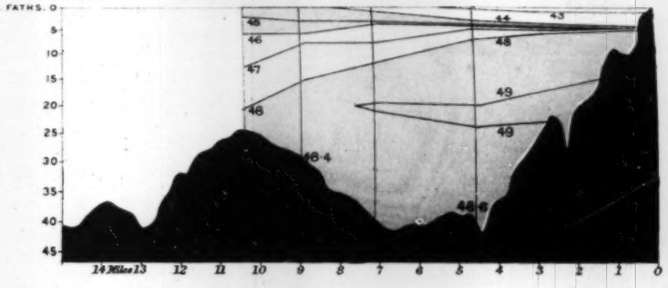
2ND DECEMBER 1887



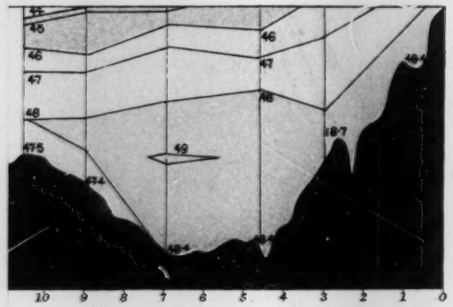
XIV 14TH DECEMBER 1887



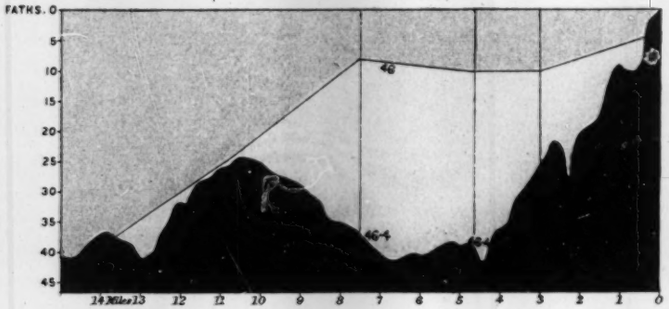
XV 15TH DECEMBER 1887



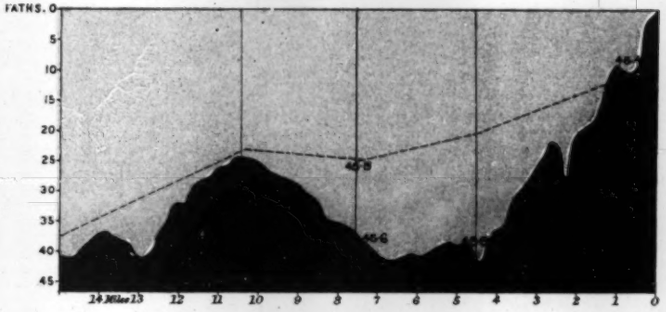
19TH DECEMBER 1887



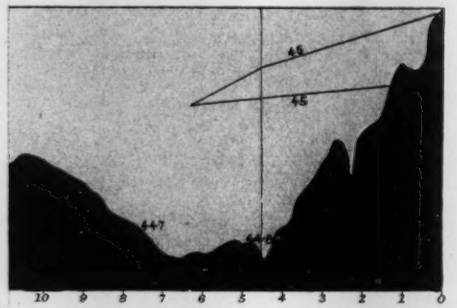
XVII 8TH JANUARY 1888



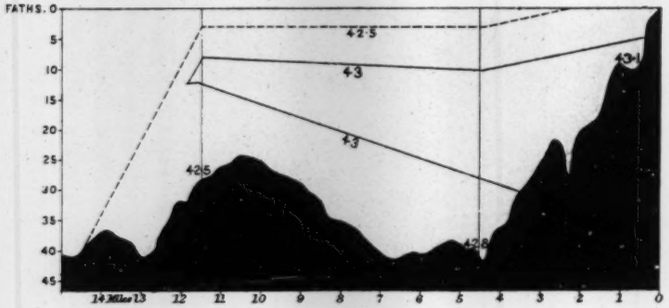
XVIII 27TH JANUARY 1888



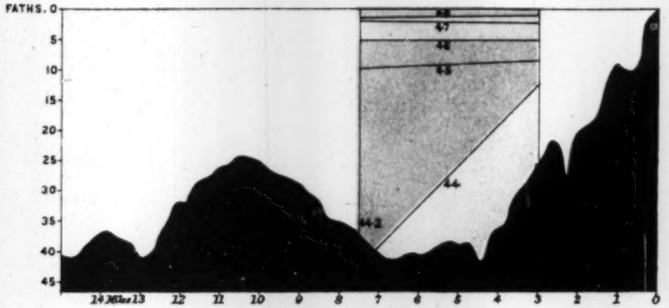
11TH FEBRUARY 1888



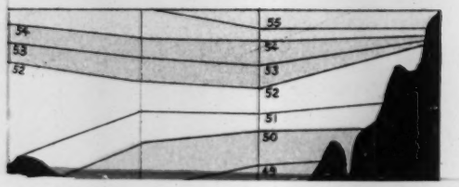
XX 29TH MARCH 1888



XXI 9TH JUNE 1888



0TH SEPTEMBER 1888

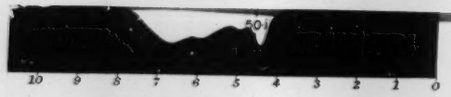


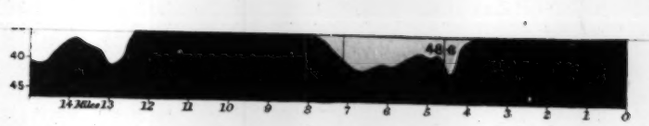
XXIII 20TH OCTOBER 1888

SCALE OF COLOURING FOR TEMPERATURE

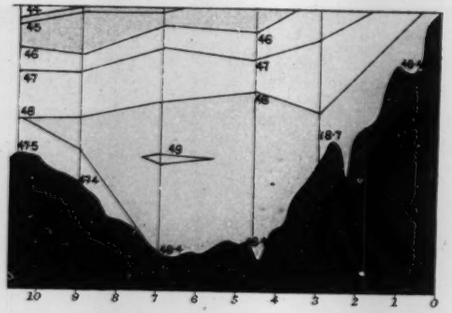
54° TO 56°
52° – 54°
50° – 52°
48° – 50°

TEMPERATURE SECTIONS OF LOCH STRIVAN

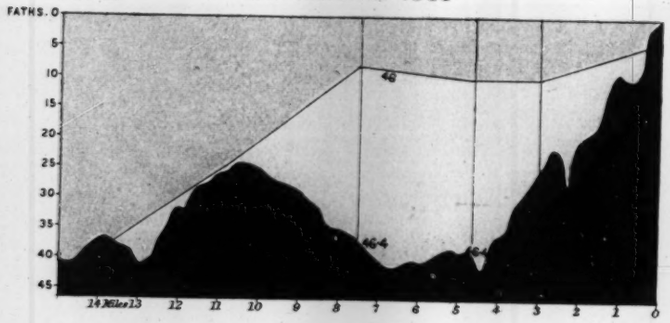




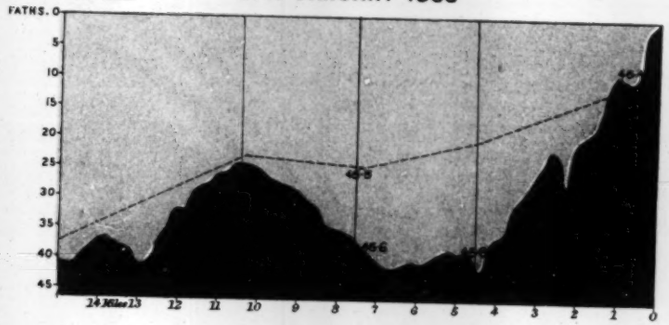
18TH DECEMBER 1887



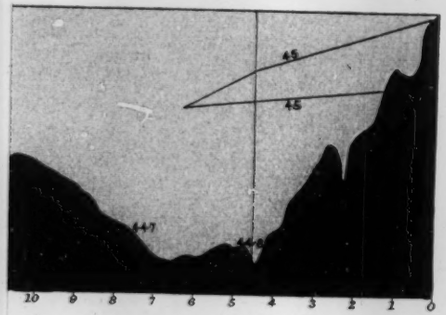
XVII 8TH JANUARY 1888



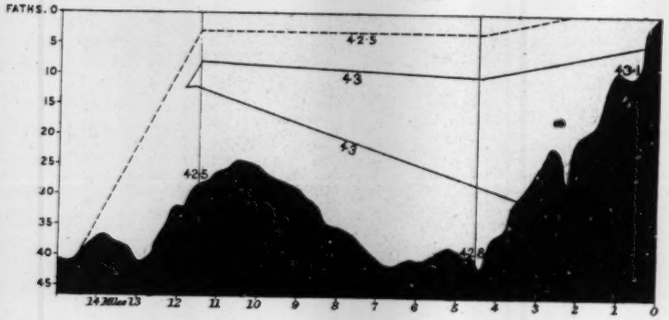
XVIII 27TH JANUARY 1888



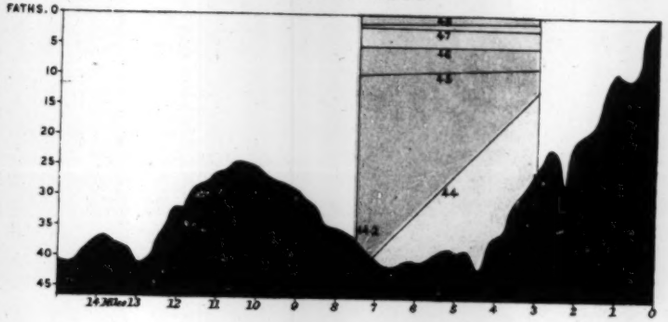
11TH FEBRUARY 1888



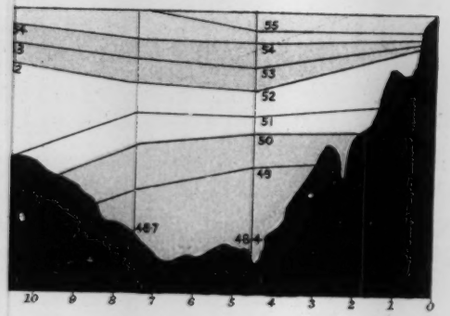
XX 29TH MARCH 1888



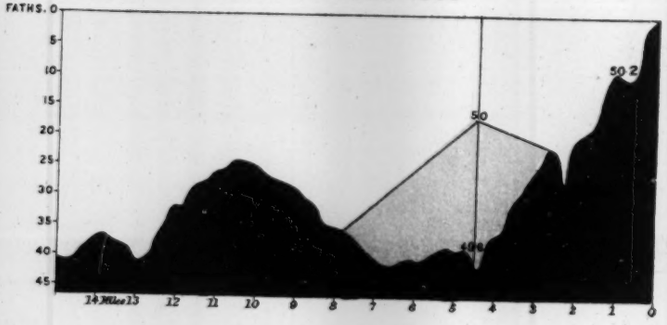
XXI 9TH JUNE 1888



TH SEPTEMBER 1888



XXIII 20TH OCTOBER 1888

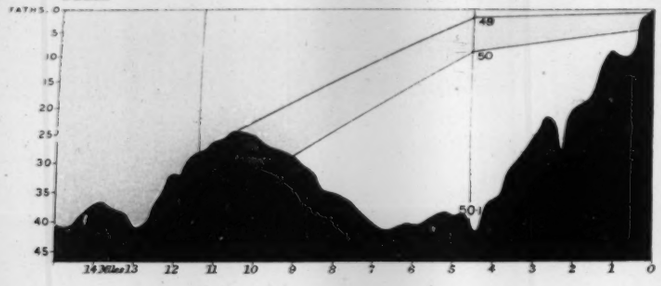


SCALE OF COLOURING FOR TEMPERATURE

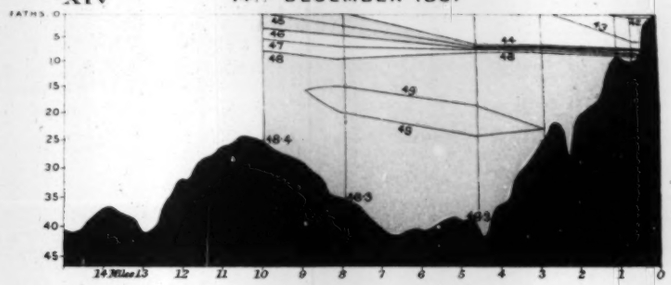
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°
44° – 46°
42° – 44°

PLATE XX

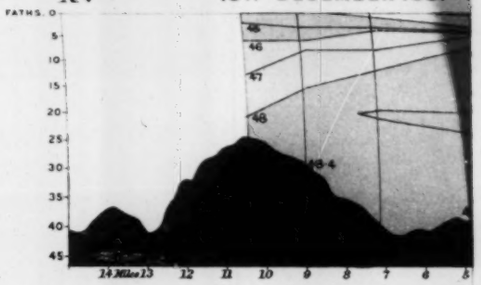
XIII 2ND DECEMBER 1887



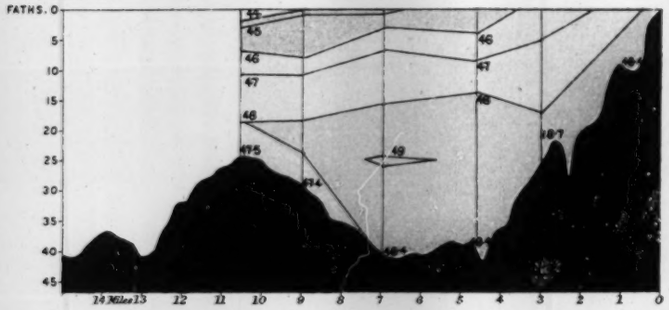
XIV 14TH DECEMBER 1887



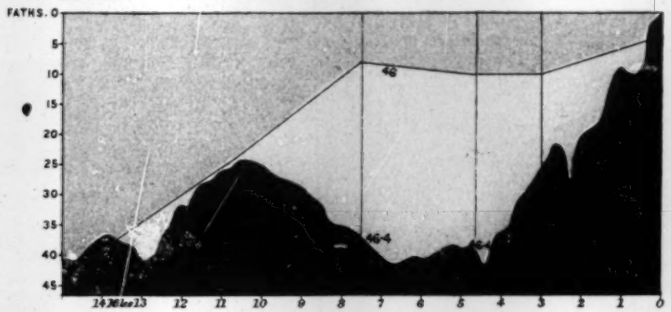
XV 15TH DECEMBER 1887



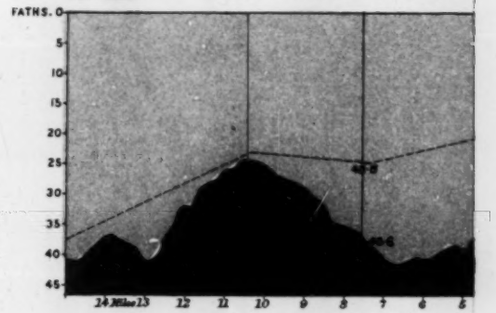
XVI 19TH DECEMBER 1887



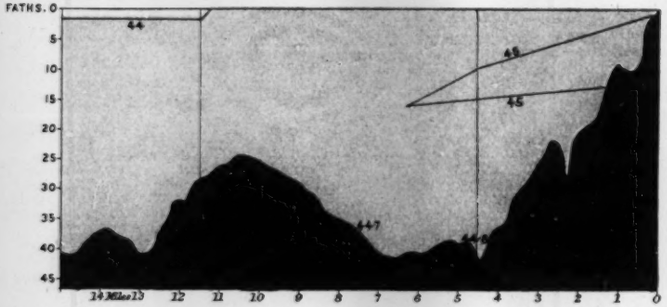
XVII 8TH JANUARY 1888



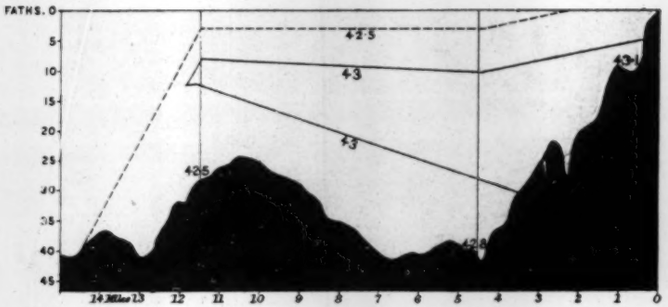
XVIII 27TH JANUARY 1888



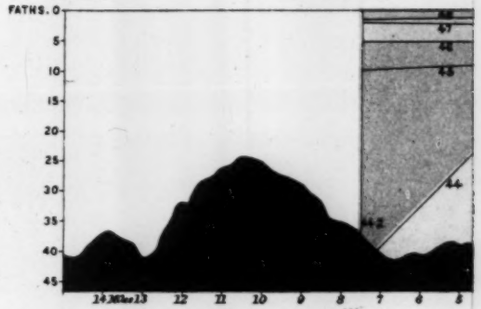
XIX 11TH FEBRUARY 1888



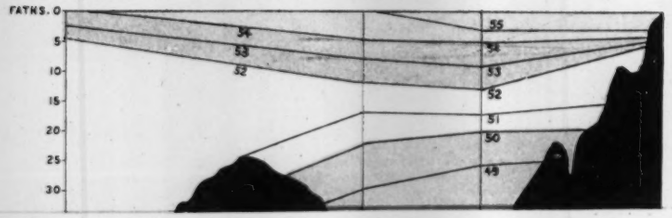
XX 29TH MARCH 1888



XXI 9TH JUNE 1888



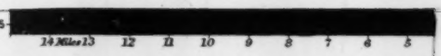
XXII 20TH SEPTEMBER 1888



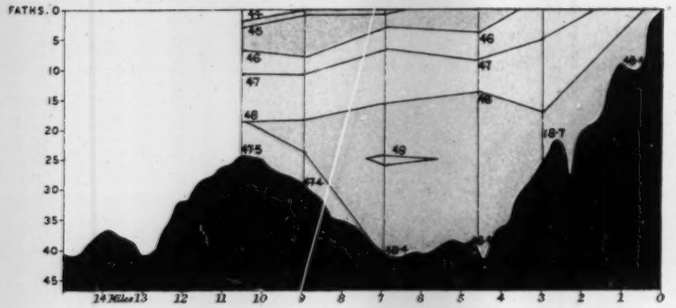
XXIII 20TH OCTOBER 1888

SCALE OF COLOURING FOR TEMPERATURE

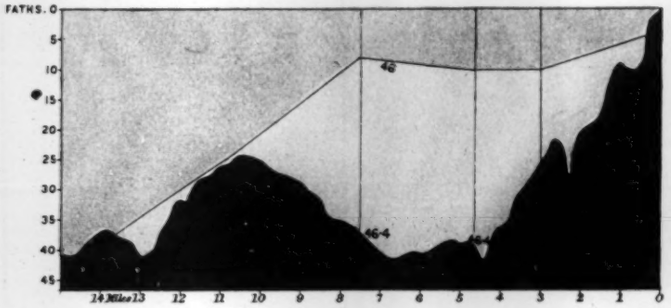
54° TO 56°
52° – 54°
50° – 52°
48° – 50°
46° – 48°



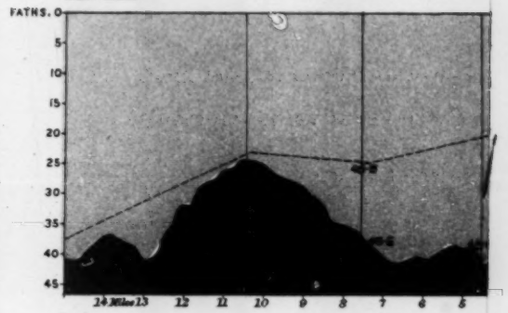
XVI 18TH DECEMBER 1887



XVII 8TH JANUARY 1888



XVIII 27TH JANUARY 1888



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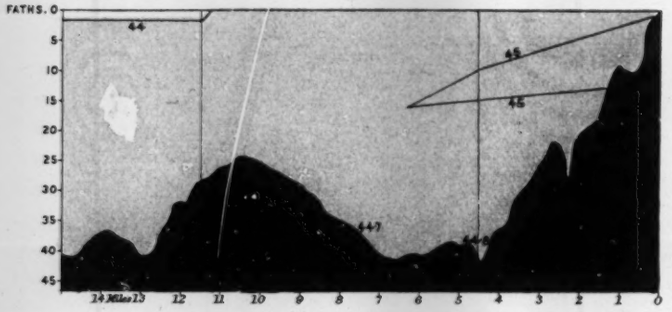
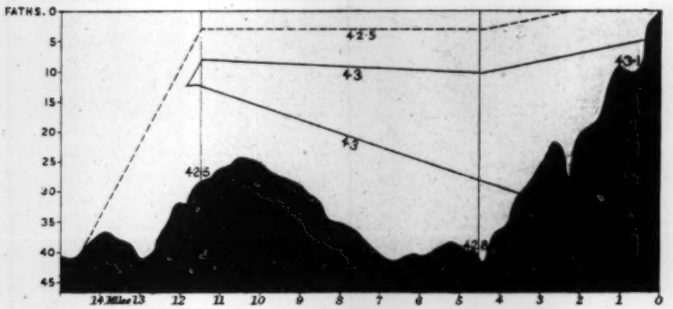
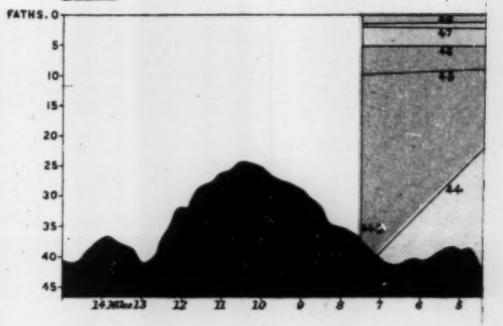


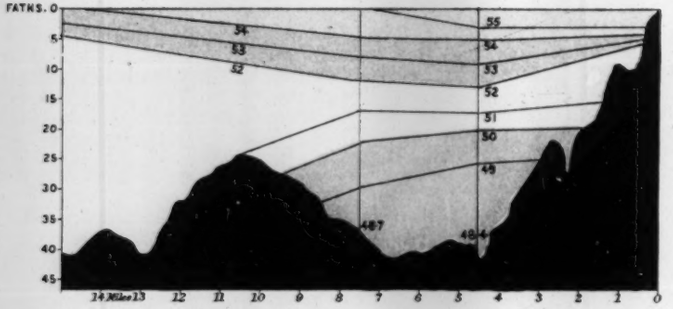
XX 29TH MARCH 1888



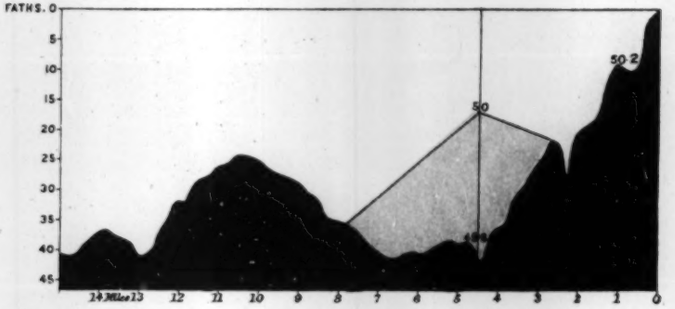
XXI 9TH JUNE 1888

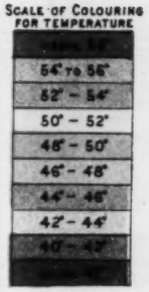


XXII 20TH SEPTEMBER 1888



XXIII 20TH OCTOBER 1888

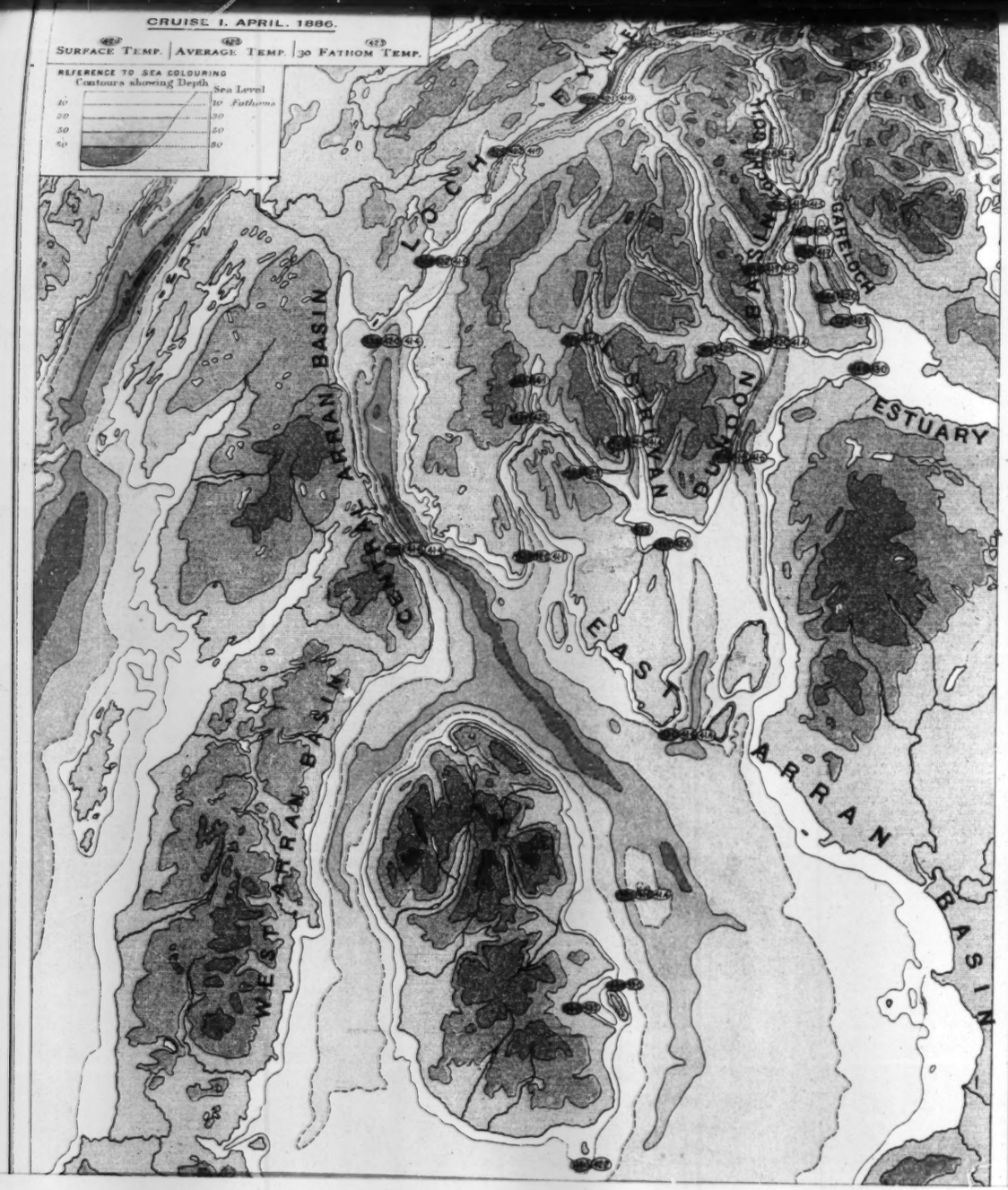


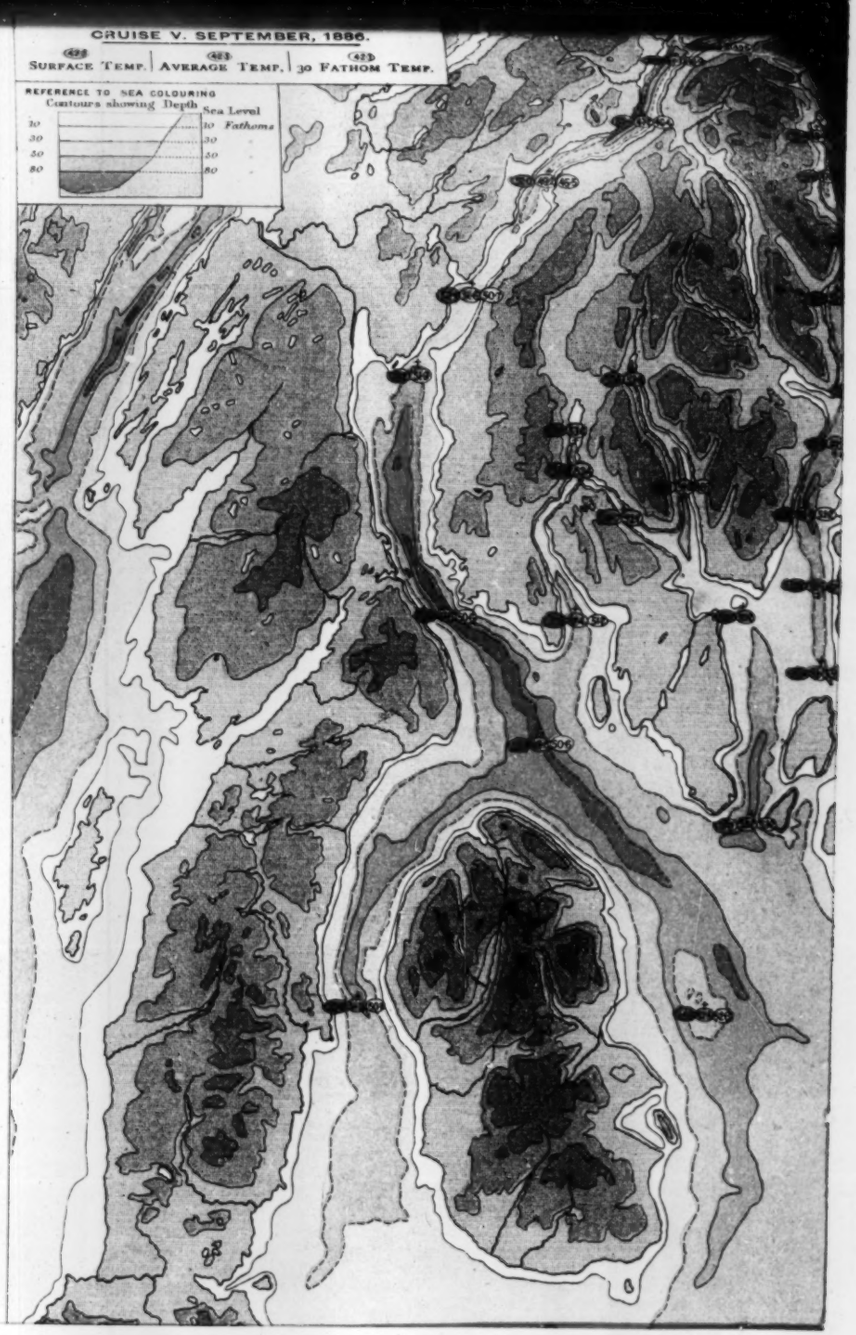


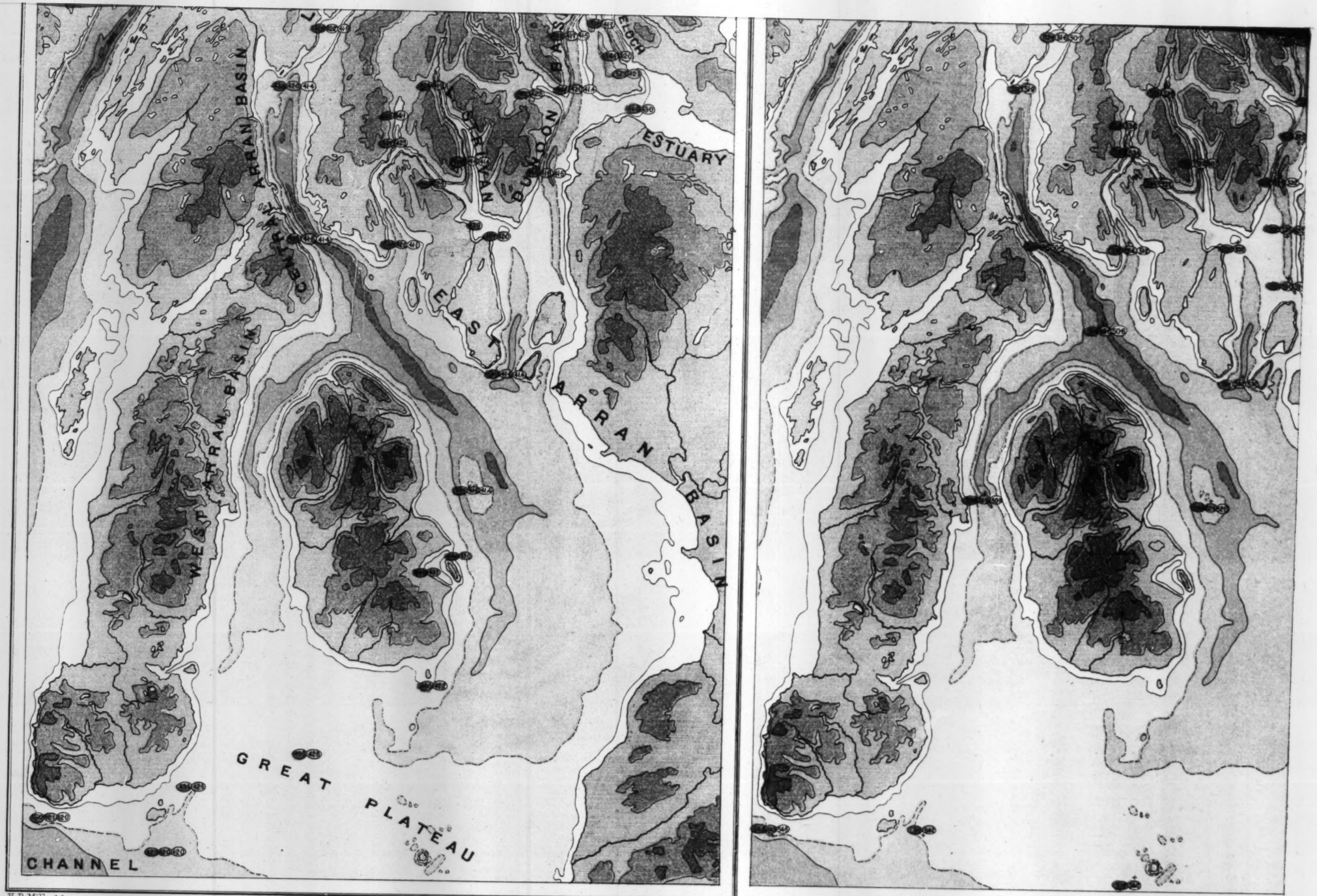
Bartholomew Edin.

I. APRIL, 1886.
AGE TEMP. | 30 FATHOM TEMP.
ING
Sea Level
10 Fathoms
30
50
80
LOCH RYAN
LOCH STRIVEN
GARELOCH
ARRAN BASIN
CLYDE ESTUARY
EAST ARRAN BASIN
WEST ARRAN BASIN
CRUISE V. SEPTEMBER, 1886.
SURFACE TEMP. | AVERAGE TEMP. | 30 FATHOM TEMP.
REFERENCE TO SEA COLOURING
Contours showing Depth
Sea Level
10 Fathoms
30
50
80

Bartholomew, Edin.r


CRUISE I. APRIL. 1886.
SURFACE TEMP.
AVERAGE TEMP.
30 FATHOM TEMP.
REFERENCE TO SEA COLOURING
Contours showing Depth
Sea Level
10 Fathoms
20
30
50
80
LOCH RYAN
GARELOCH
ESTUARY
ARRAN BASIN
CUMBRAE
EAST ARRAN BASIN
WEST ARRAN BASIN


CRUISE V. SEPTEMBER, 1886.
SURFACE TEMP.
AVERAGE TEMP.
30 FATHOM TEMP.
REFERENCE TO SEA COLOURING
Contours showing Depth
Sea Level
10 Fathoms
20
30
50
80


ARRAN BASIN
CENTRAL
KILBRANNAN SOUND
ESTUARY
EAST ARRAN BASIN
WEST ARRAN BASIN
GREAT PLATEAU
CHANNEL

H.R.Mill. *delt*

Fig. 1.

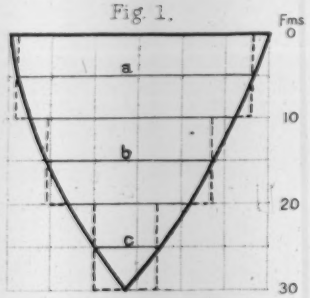


Fig. 2. **CLYDE SEA AREA—SEASONAL VARIATIONS OF AIR TEMPERATURE.**

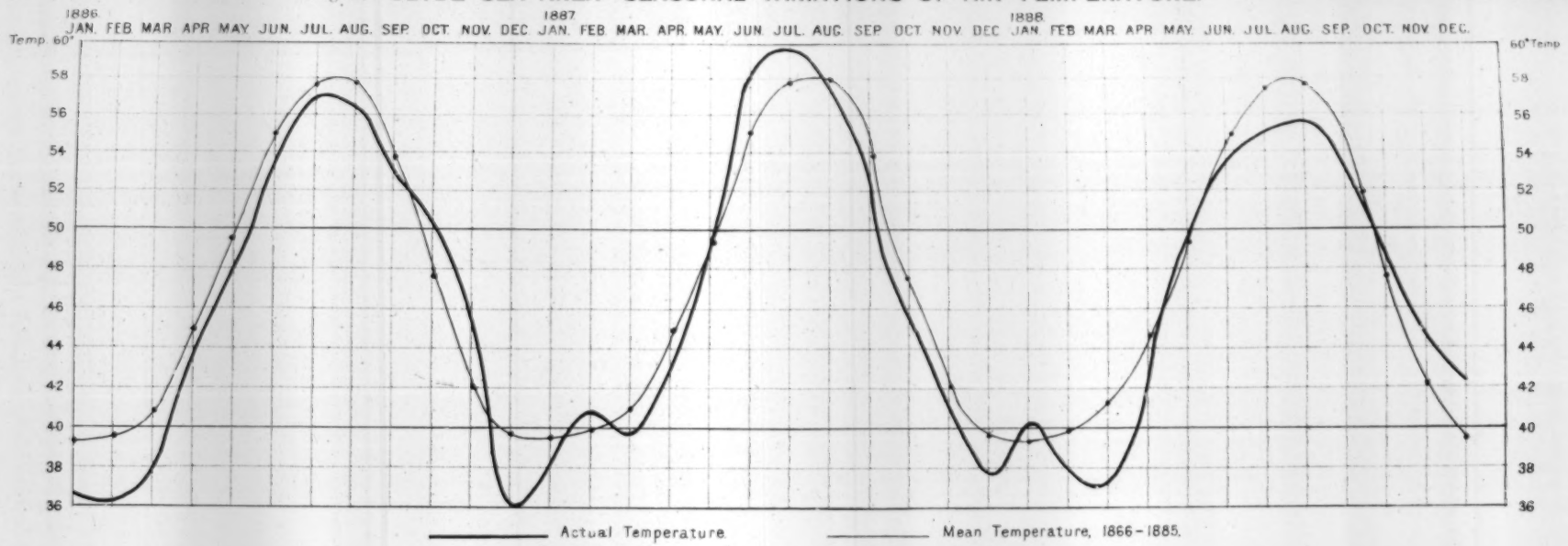
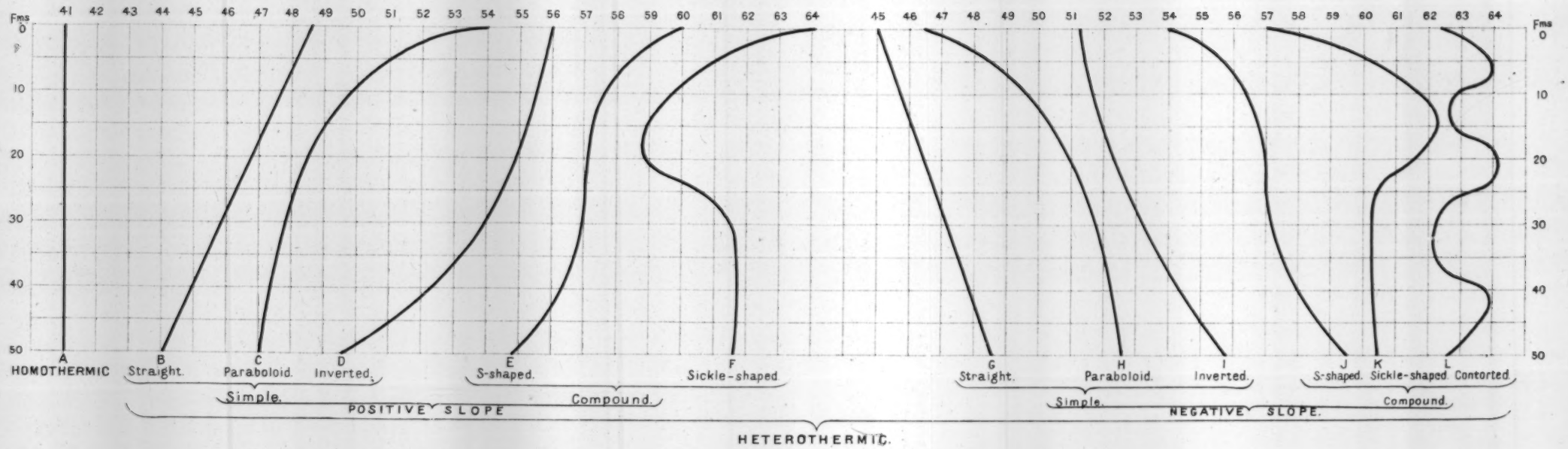


Fig. 3. **TYPES OF VERTICAL TEMPERATURE CURVES.**



TEMPERATURE CURVES

PLATE XXII

TEMPERATURE CURVES

Fig. 4 CHANNEL.—TYPICAL CURVES.

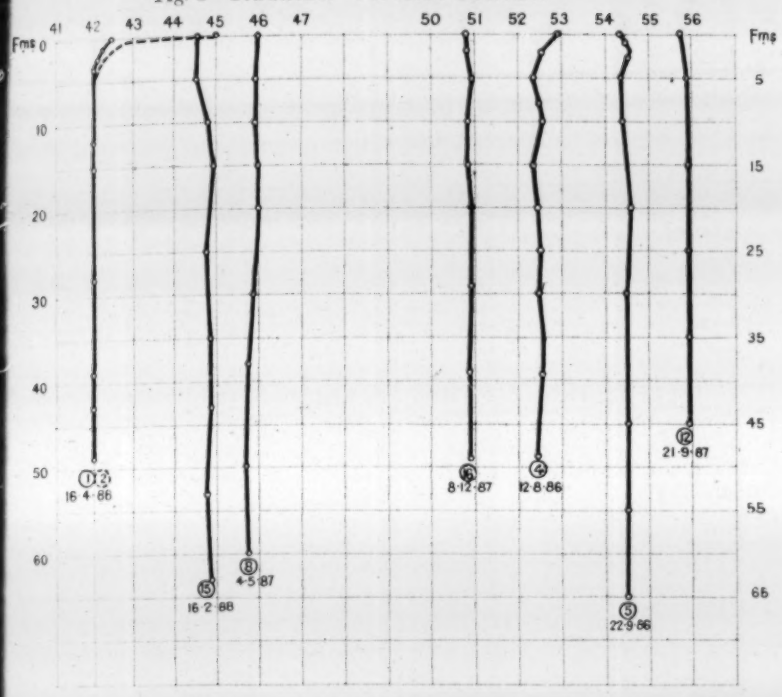


Fig. 5 MINCH AND NORTH ATLANTIC TYPES.

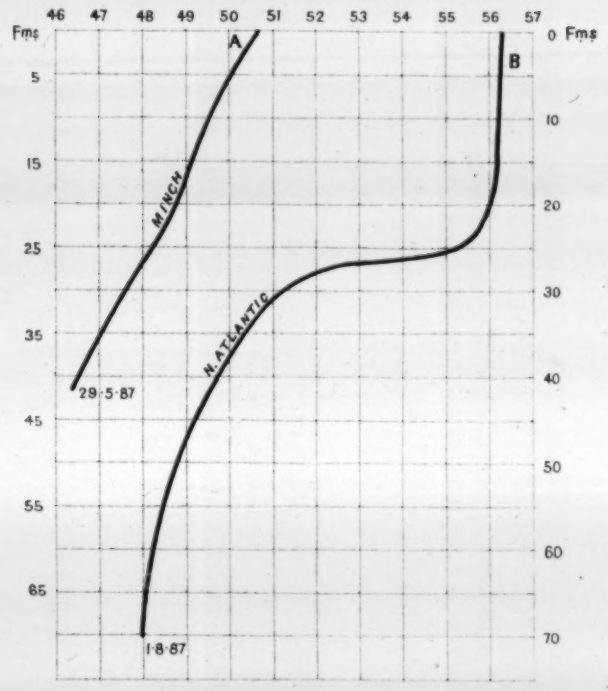
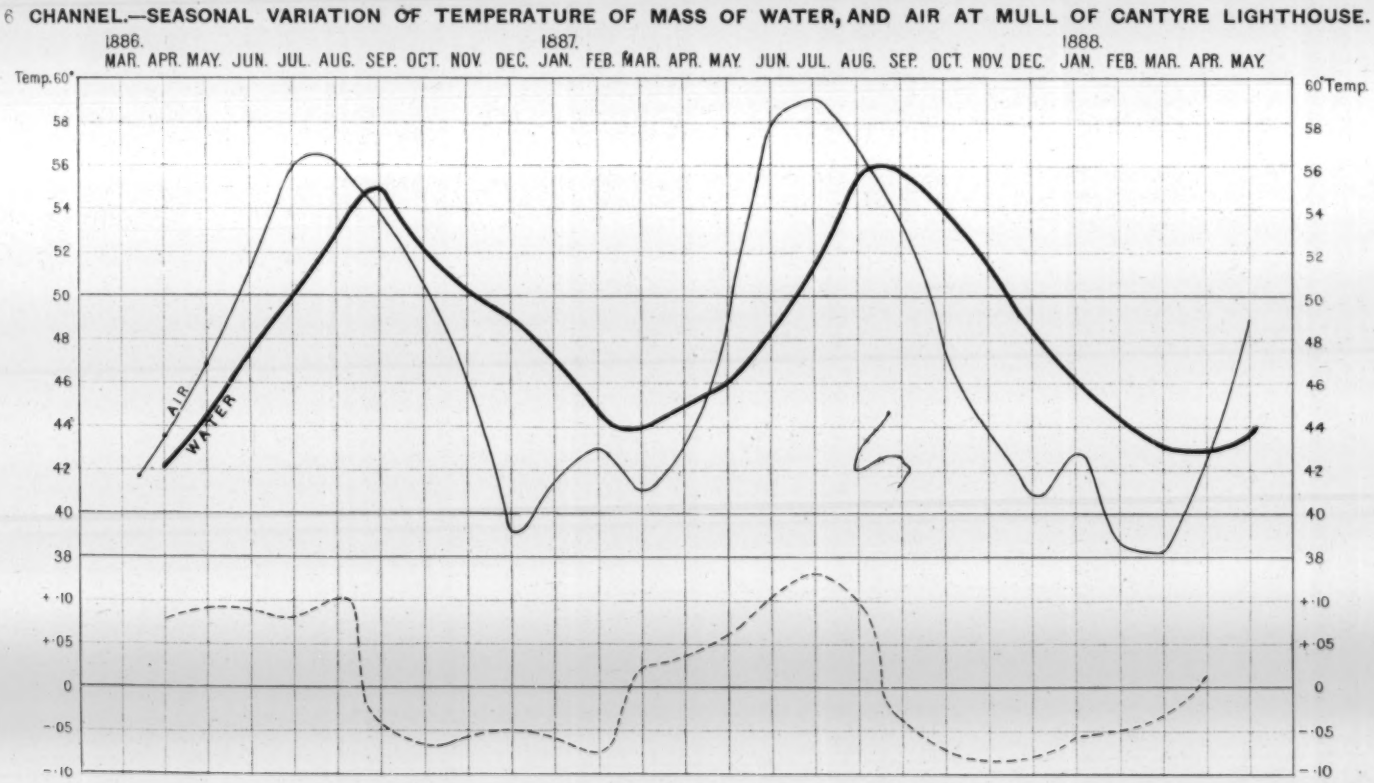
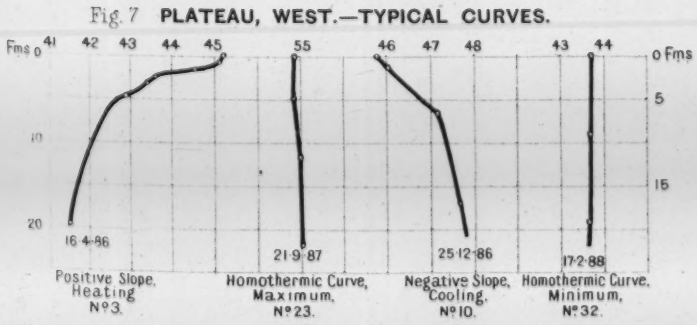


Fig. 6 CHANNEL.—SEASONAL VARIATION OF TEMPERATURE OF MASS OF WATER, AND AIR AT MULL OF CANTYRE LIGHTHOUSE.



Curve of Rate of Change of Water Temperature in degrees per day (averages per month)

Fig. 7 PLATEAU, WEST.—TYPICAL CURVES.



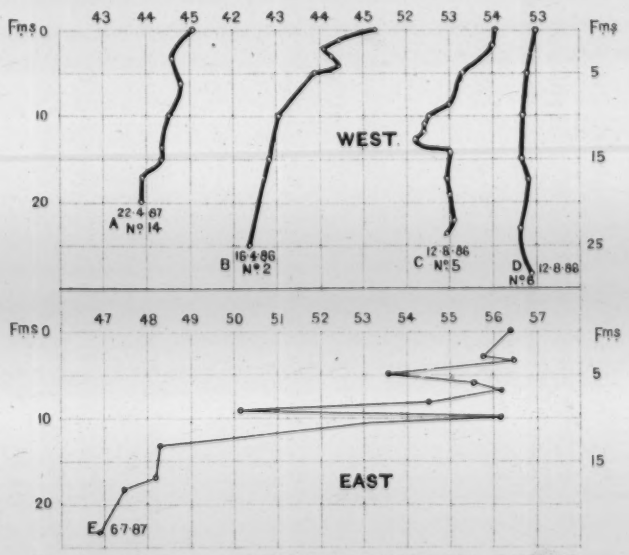


Fig. 8 PLATEAU, CONTORTED VERTICAL CURVES.

TEMPERATURE CURVES AND SECTIONS

Fig. 9 **PLATEAU, WEST. Hourly Observations—Curves for Various Depths.**

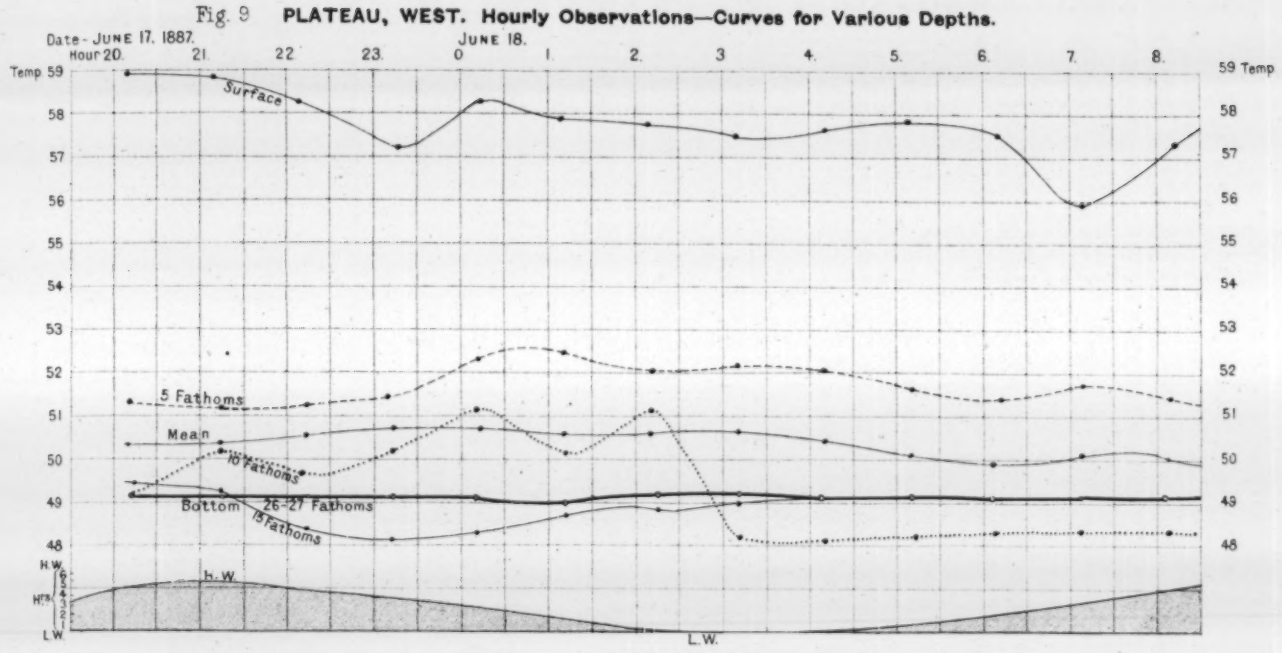


Fig. 10 **PLATEAU, WEST. Vertical Curves**

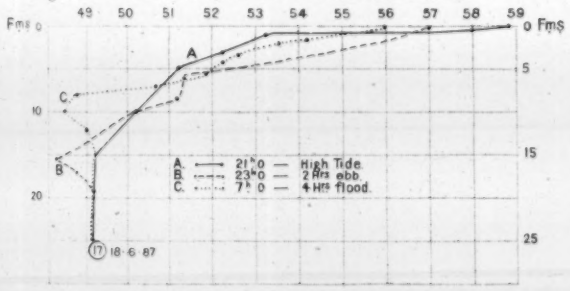


Fig. 12 **Rough Section—Brodick to Irvine, 20th September, 1887.**

(Not drawn to scale.)

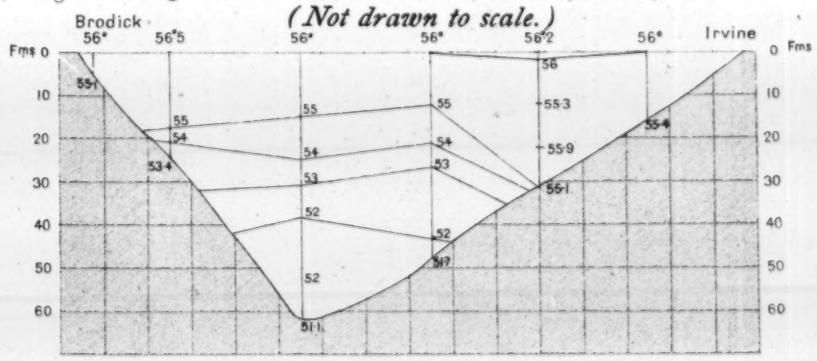


Fig. 11 **Exceptional Curves, Largybeg.**

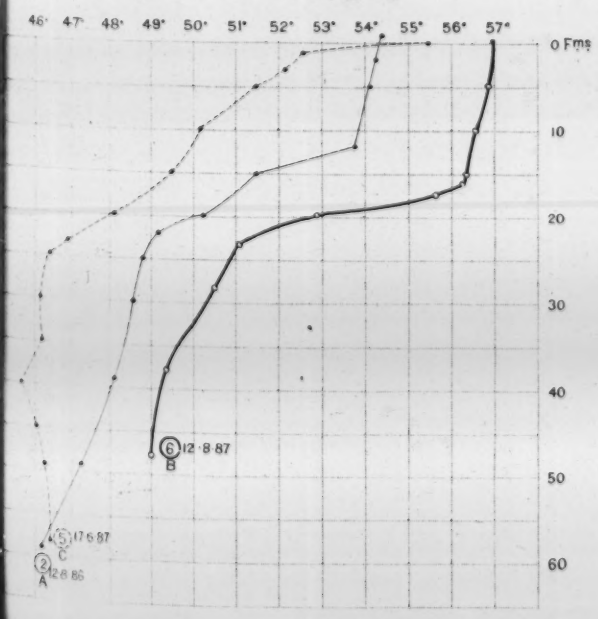


Fig. 13

Change of Slope at Maximum.

Garroch Head

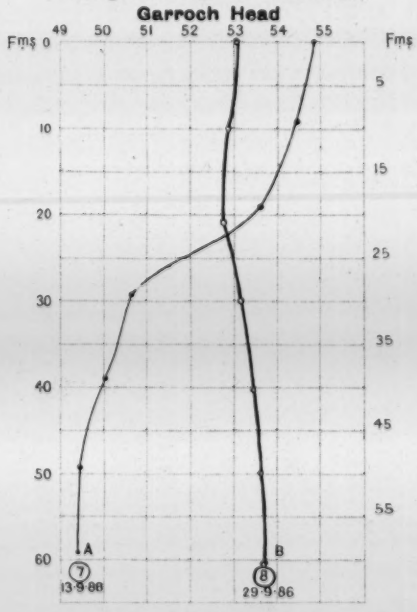
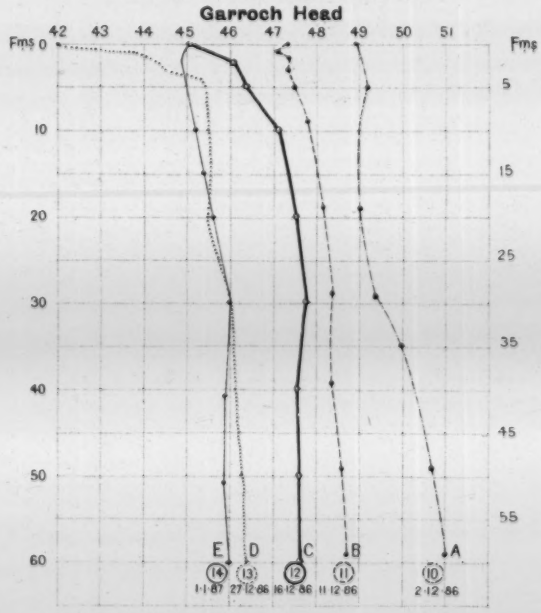


Fig. 14

Cooling Curves, Negative Slope.

Garroch Head



TEMPERATURE CURVES

Fig. 15.

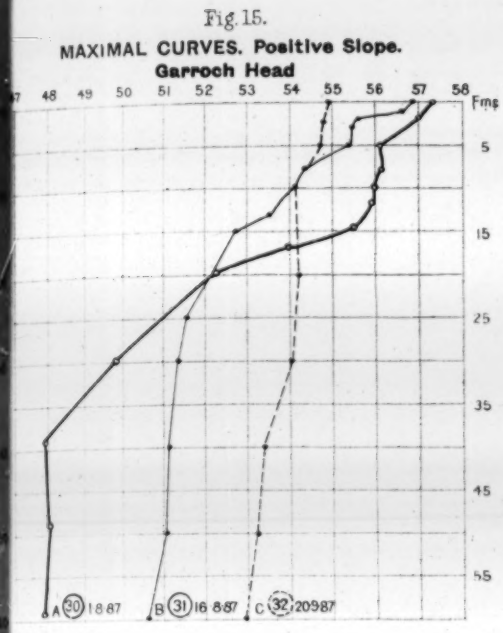


Fig. 16.

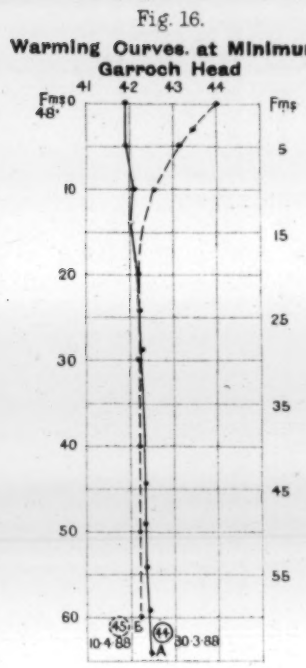


Fig. 17

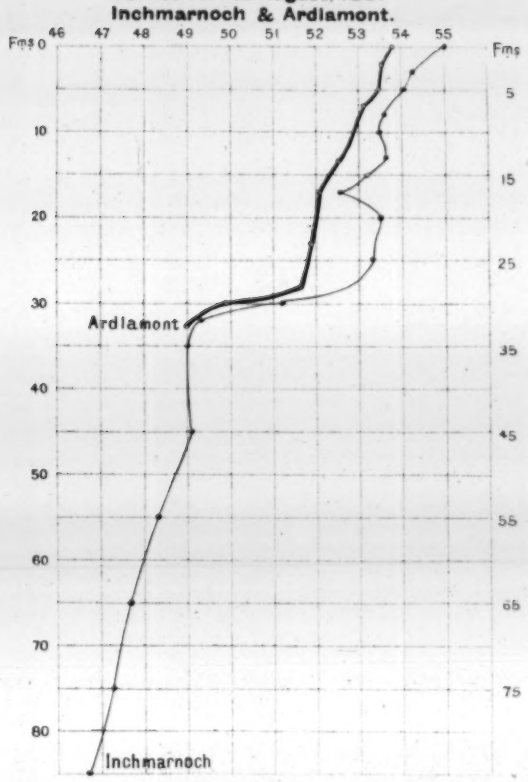


Fig. 18.

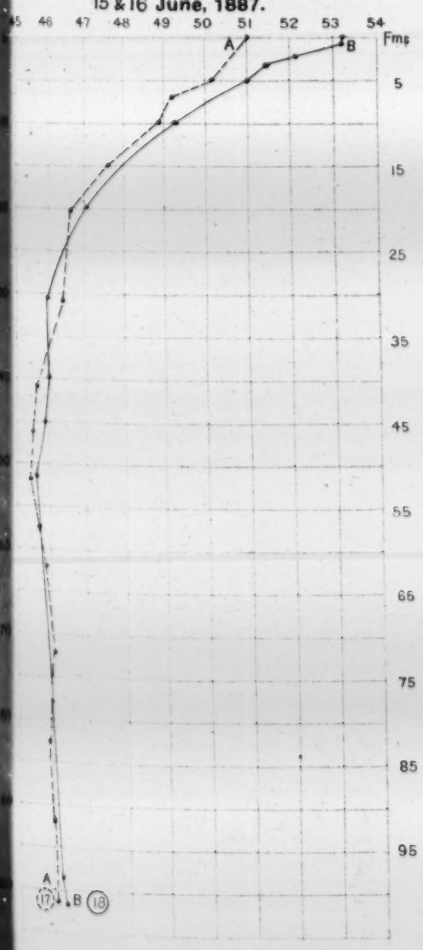


Fig. 19.

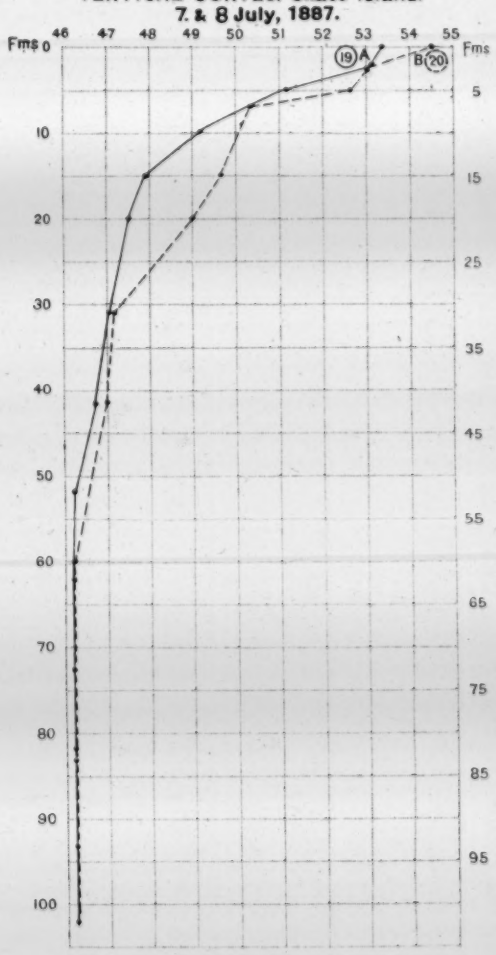
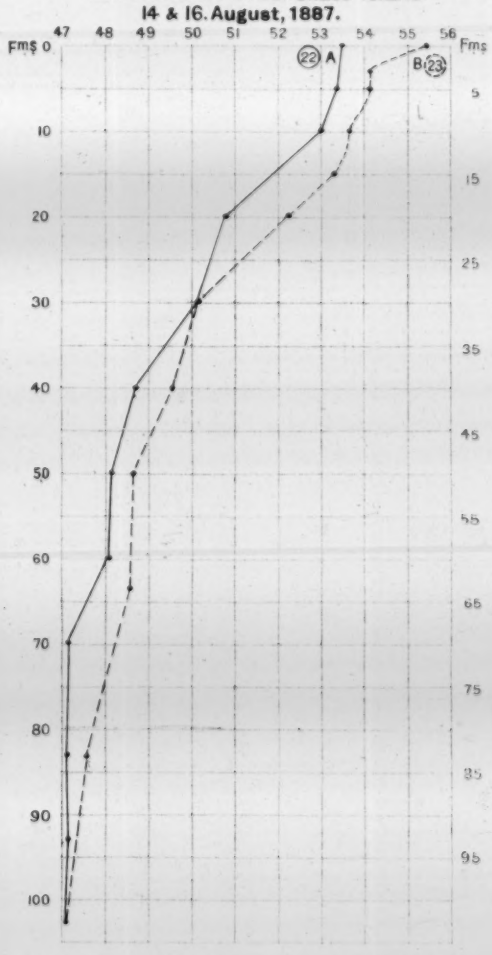


Fig. 20.



TEMPERATURE SECTIONS AND CURVES

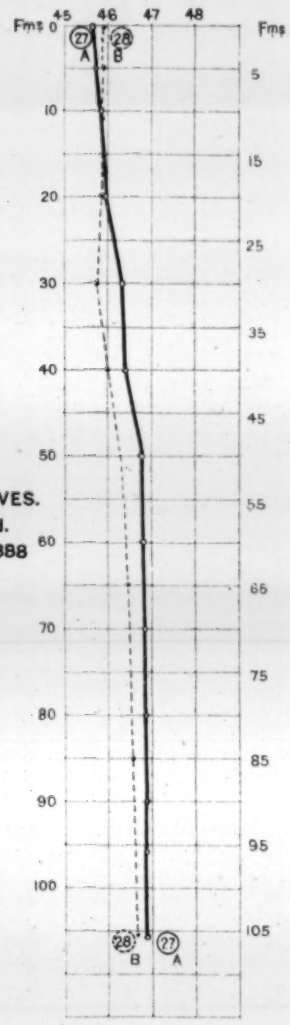


Fig. 21.
VERTICAL CURVES.
Skate Island.
2 & 7 January. 1888

Fig. 22 **CROSS SECTION—Central Arran Basin.**
Through Greatest Depth.
23 September, 1887.

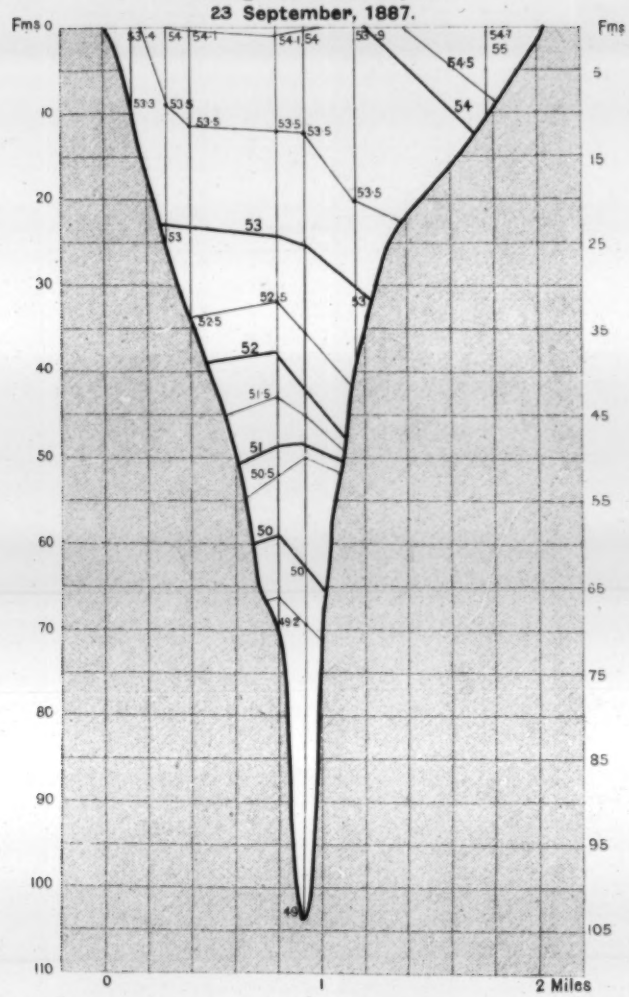
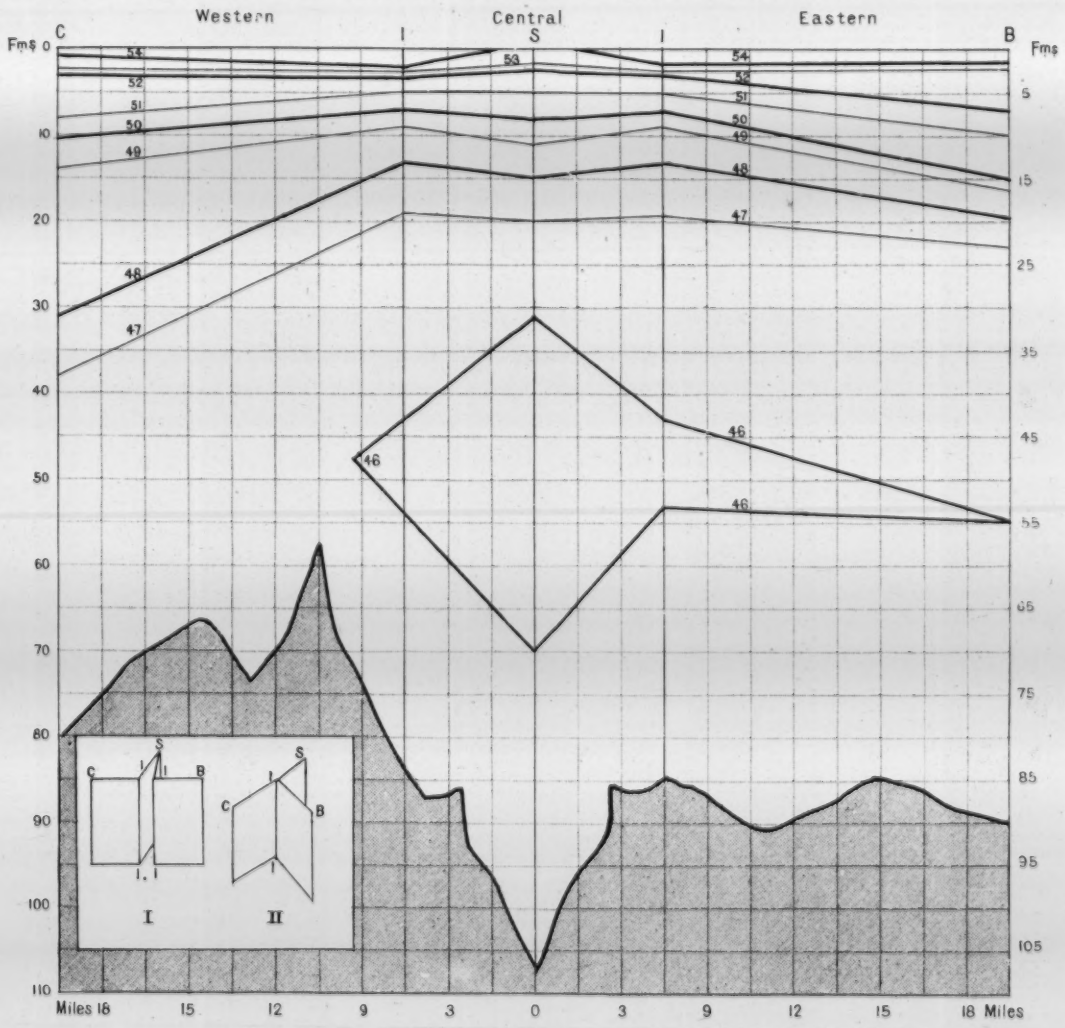


Fig. 23 **ARRAN BASIN, COMPOUND TEMPERATURE SECTION JUNE. 1887**



TEMPERATURE SECTIONS AND CURVES

Fig. 24 **ARRAN BASIN, COMPOUND TEMPERATURE SECTION—September, 1887**

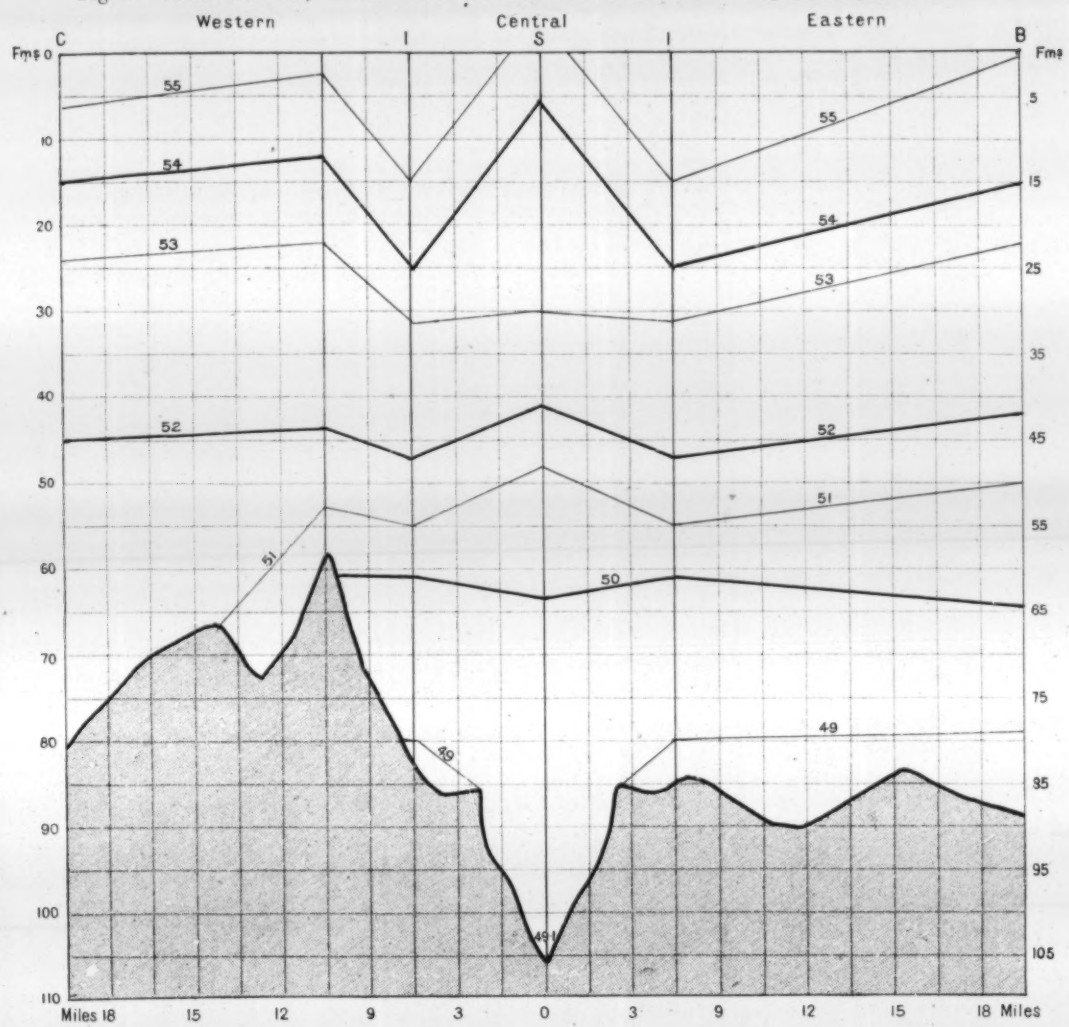
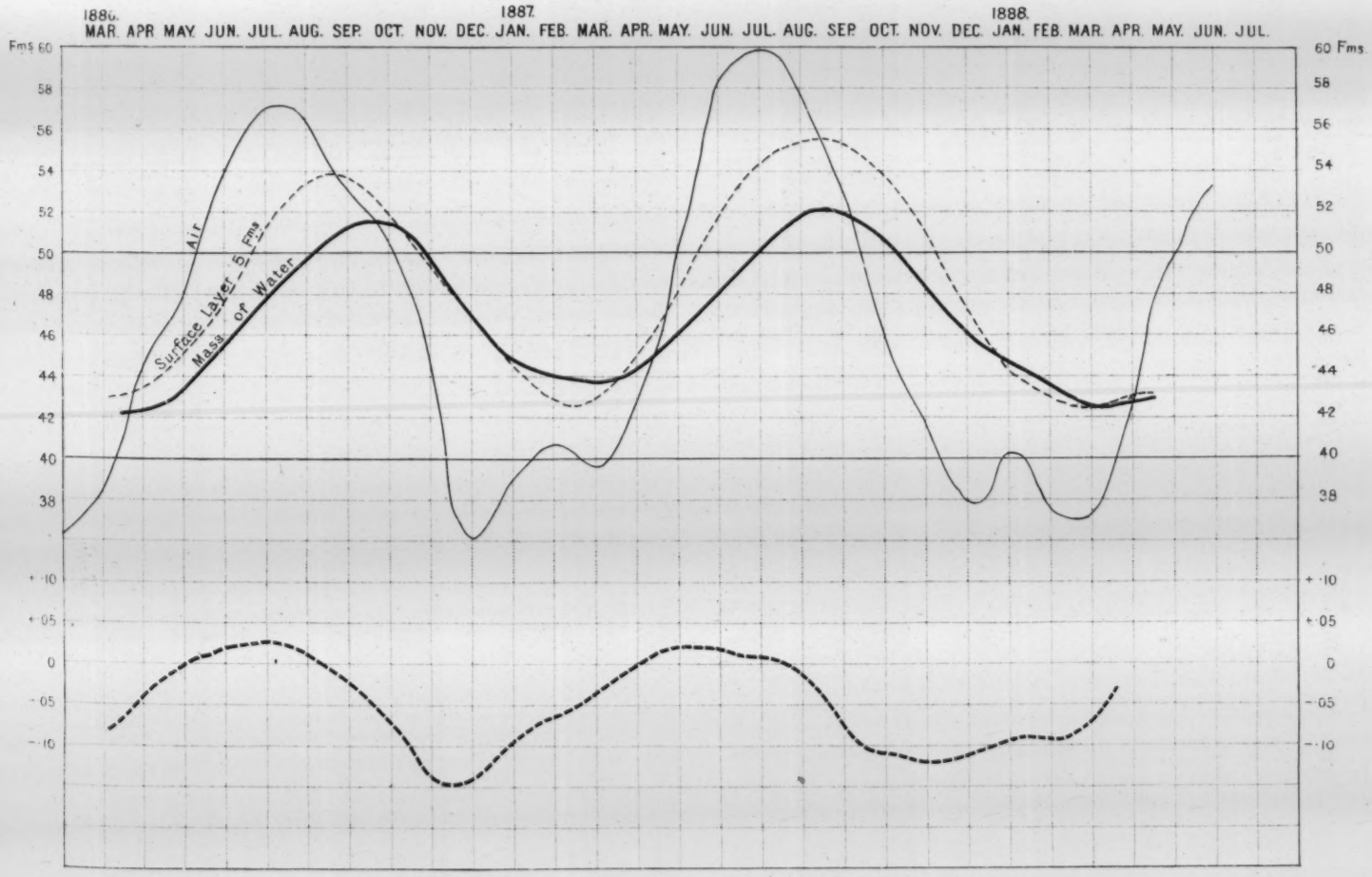


Fig. 25 **-ARRAN BASIN, Seasonal Variations of Temperature of Water and Air.**



Curve of Rate of Change of Water Temperature in degrees per day (averages per month)

TEMPERATURE CURVES

Fig. 26. OTTER II._Typical Curves.

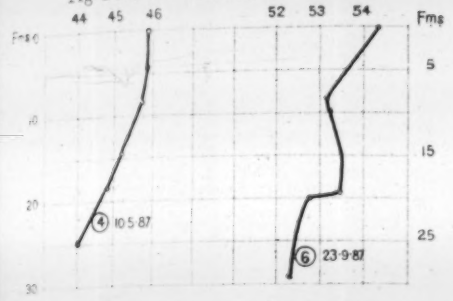


Fig. 27. GORTANS._Typical Curves.

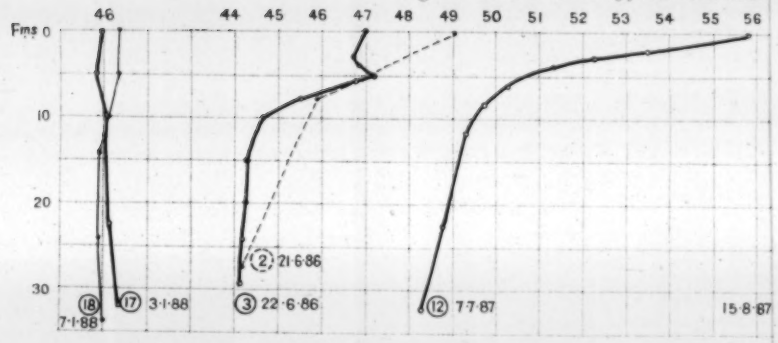


Fig. 28. FURNACE._Typical Curves.

Fig. 29. STRACHUR,
Curves for 19 & 20 April, 1886.

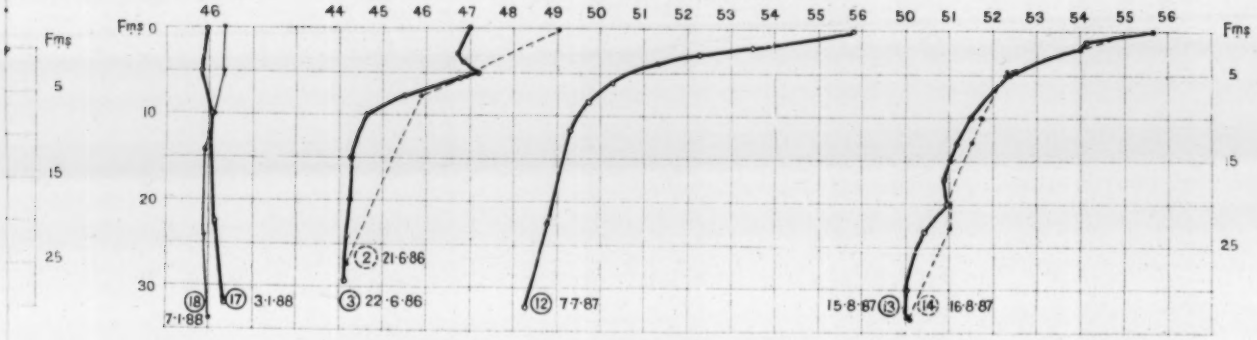
Fig. 31. STRACHUR
Curves for 16 & 18 October, 1888.

Fig. 32. INVERARAY
Curves for 16. & 17. September, 1886.

Curve

TEMPERATURE CURVES

Fig. 27. **GORTANS—Typical Curves.**



.Typical Curves.

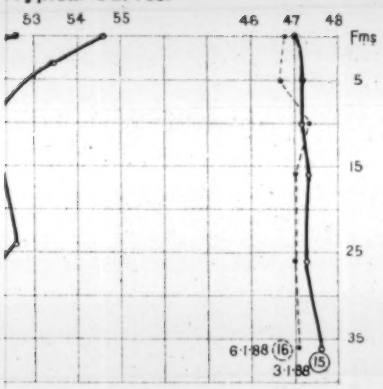


Fig. 29. **STRACHUR,**
Curves for 19. & 20. April, 1886.

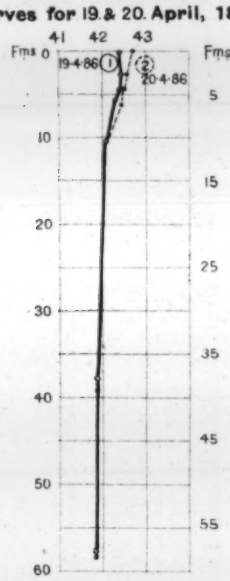


Fig. 30. **STRACHUR,**
Curves for 5. & 7. November, 1887.

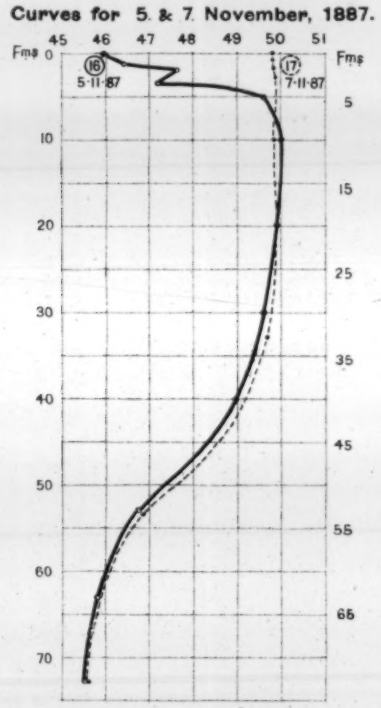


Fig. 32. **INVERARAY**
Curves for 16. & 17. September, 1886.

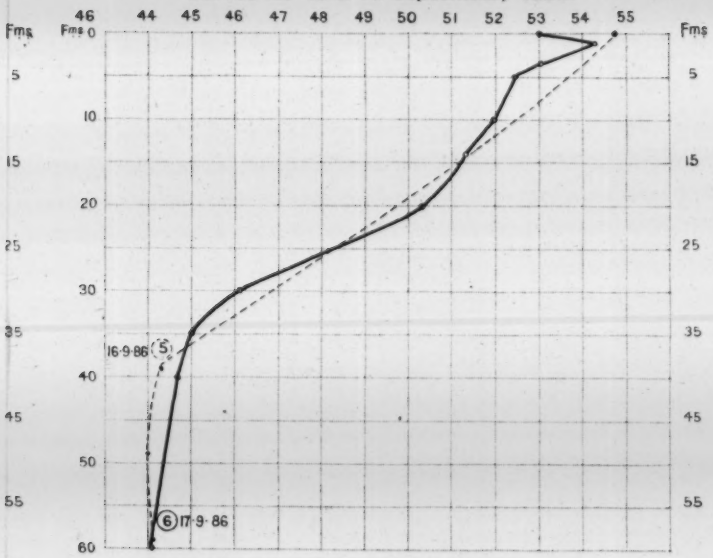
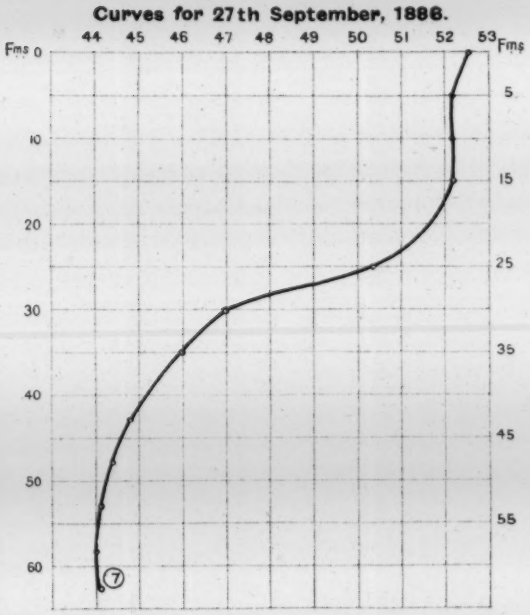


Fig. 33. **INVERARAY**
Curves for 27th September, 1886.



TEMPERATURE CURVES
LOCH FYNE

Fig. 34. **INVERARAY**

Curves for 25 & 27 August, 1888.

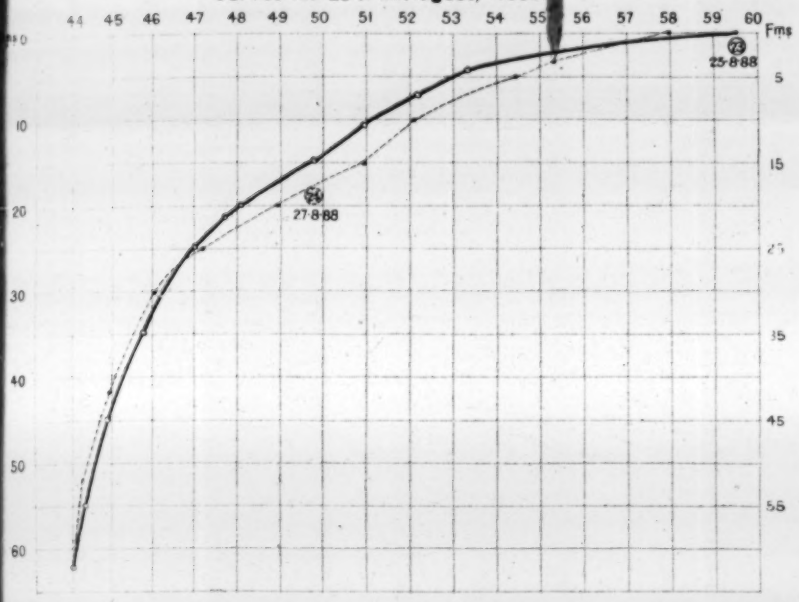


Fig. 35. **INVERARAY**

Curves for 26 August and 3. September, 1888

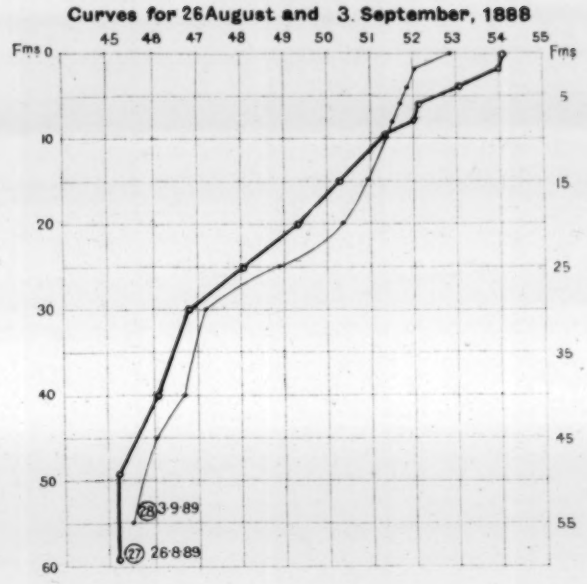


Fig. 36. **DUNDERAWE—Typical Curves.**

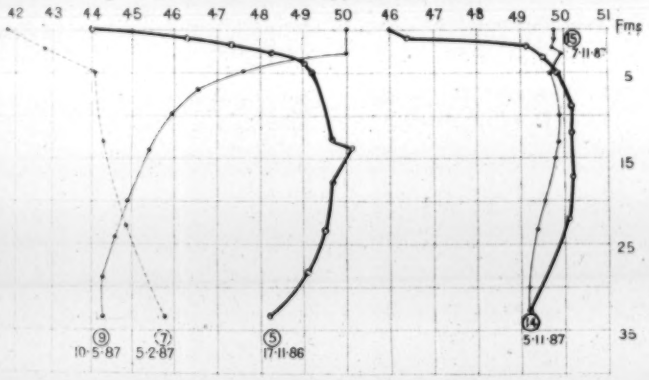


Fig. 37. **DUNDERAWE—Typical Curves.**

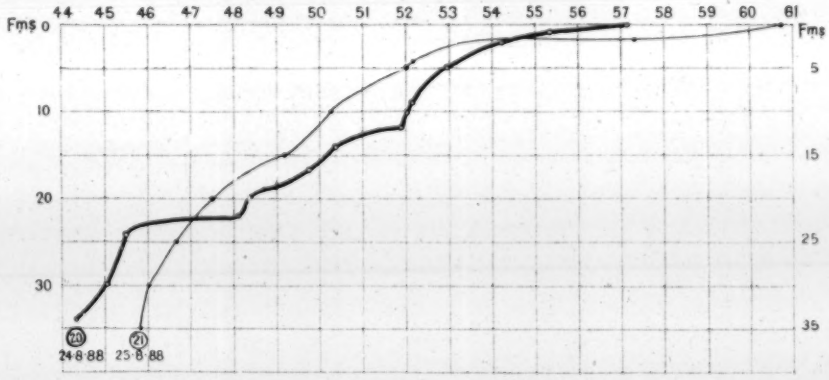


Fig. 38. **CUILL—Typical Curves.**

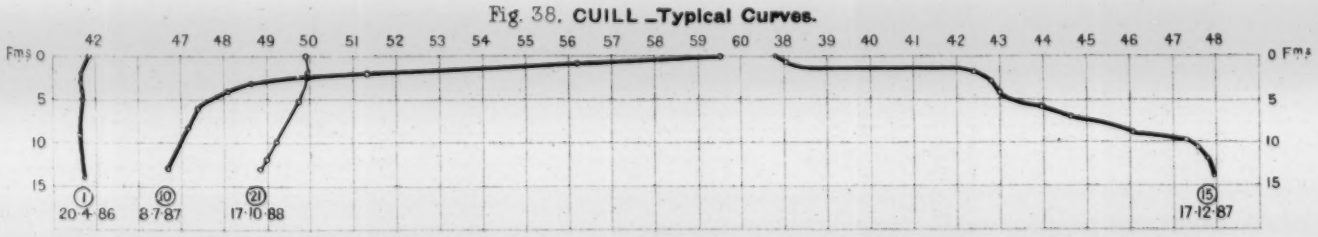


Fig. 39

First Stage in Hypothetical Circulation of Water by up-loch Wind.

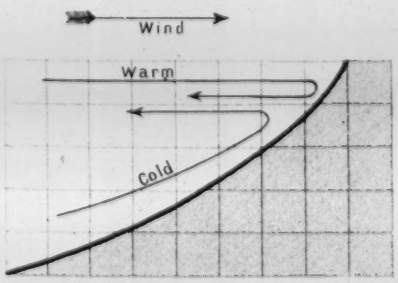
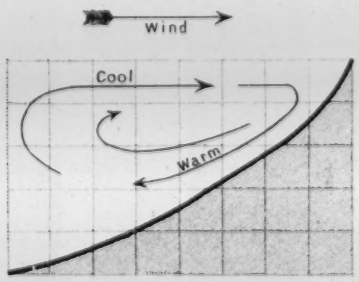


Fig. 40

Hypothetical circulation of Water by long continued up-loch Wind.



TEMPERATURE CURVES

Fig. 41 **LOCH FYNE Seasonal Variations of Temperature of Water and Air.**

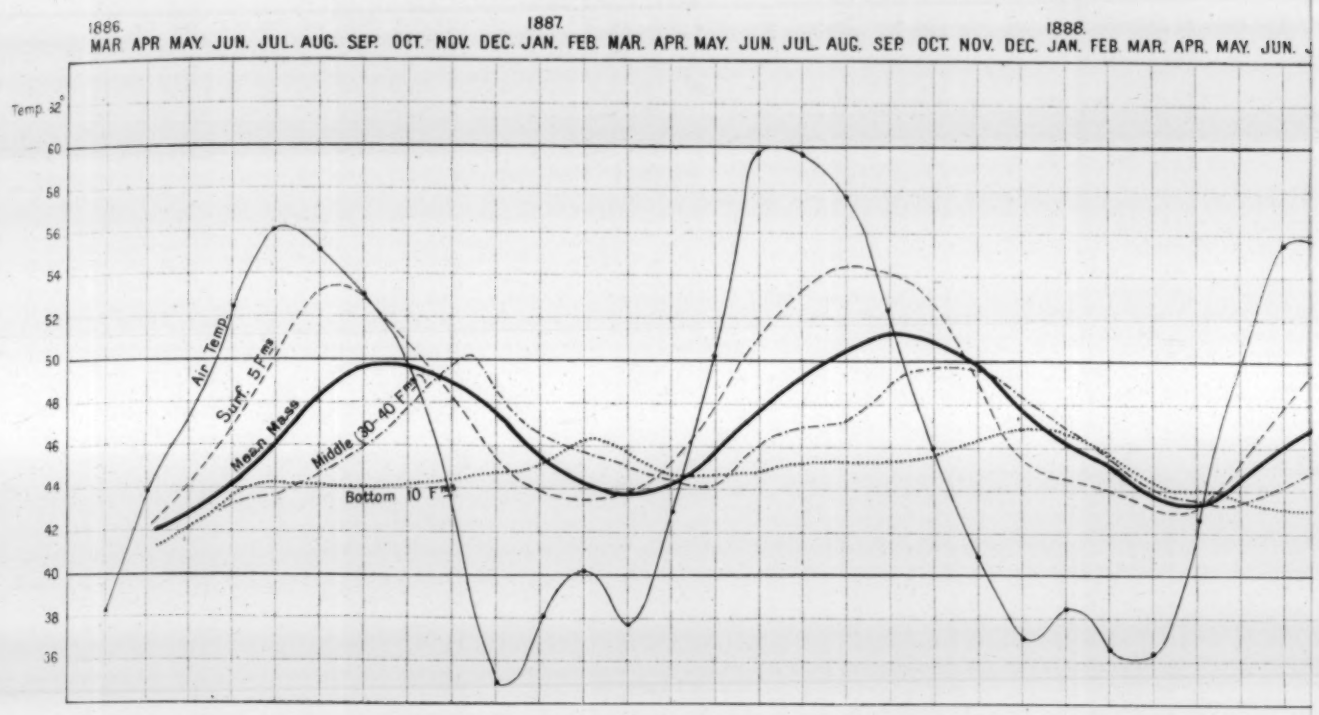


Fig. 42. **LOCH FYNE – Retardation of Annual Maximum with depth.**

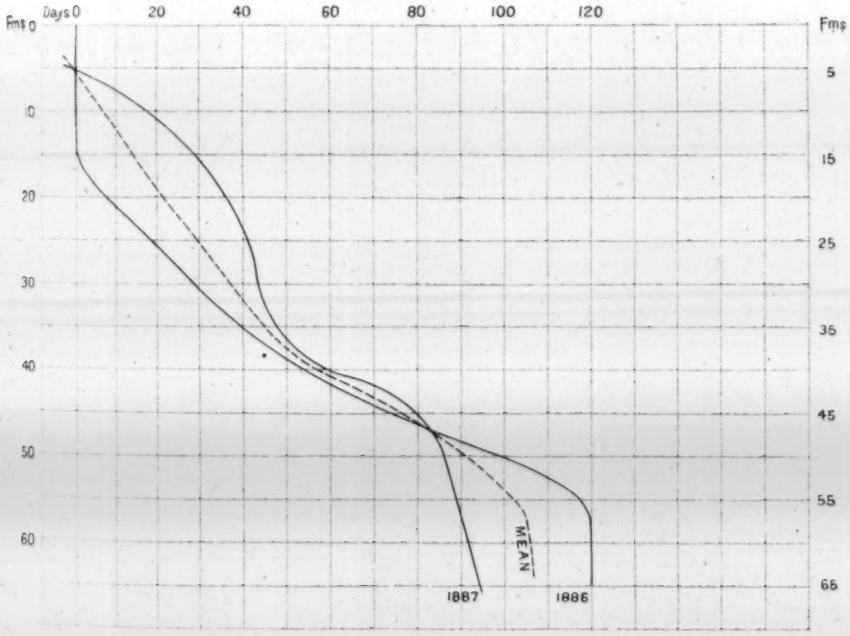


Fig. 43. **Rate of Change of Temperatu**
In Loch Fyne and

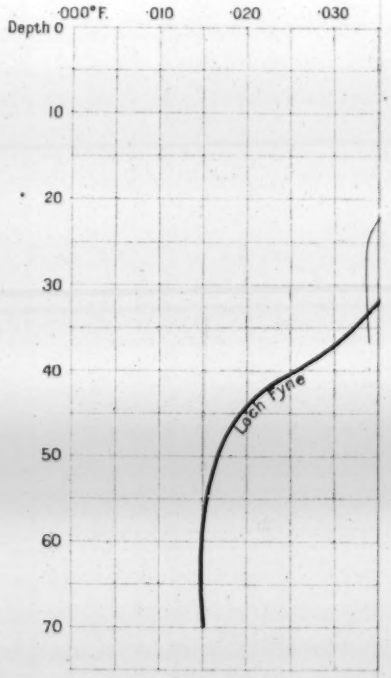
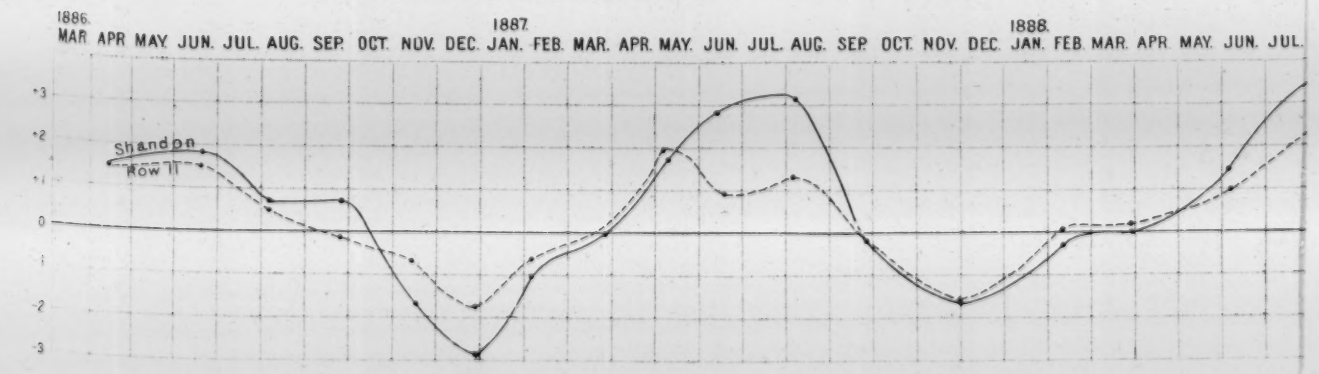


Fig. 44. **Seasonal Change of Slope in Gareloch Temperature Curves.**



TEMPERATURE CURVES

LOCH FYNE Seasonal Variations of Temperature of Water and Air.

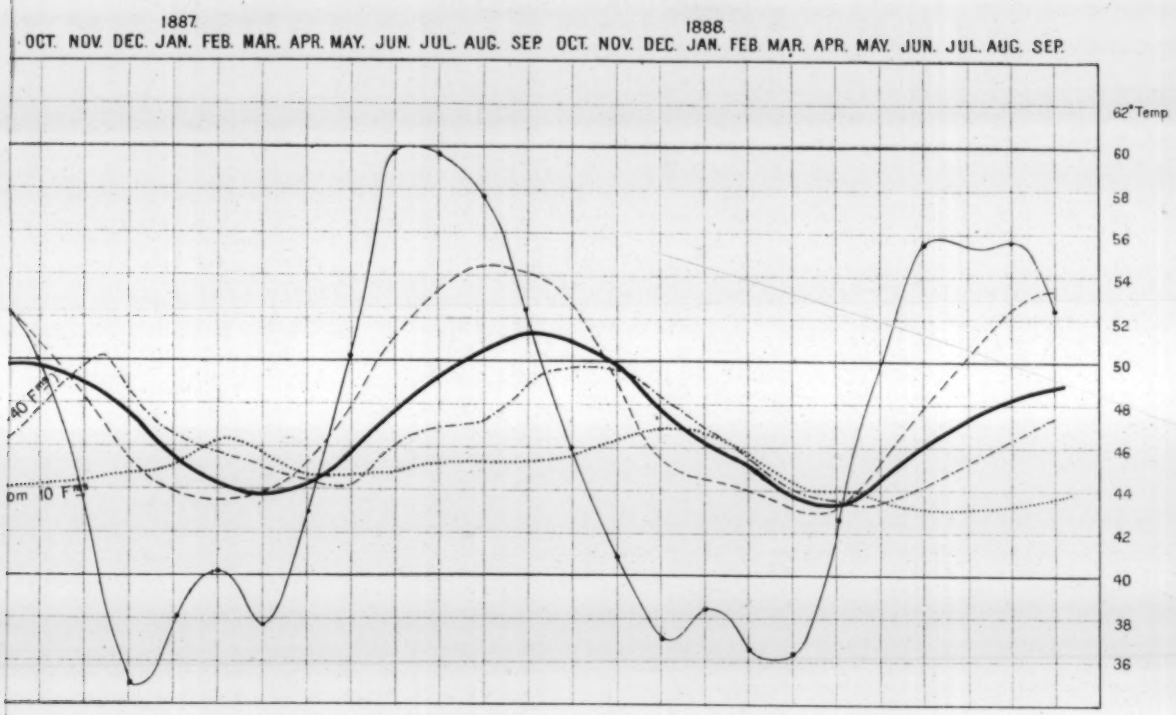
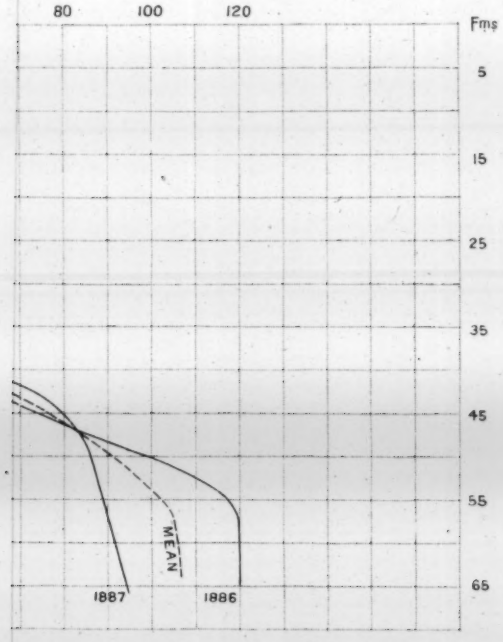
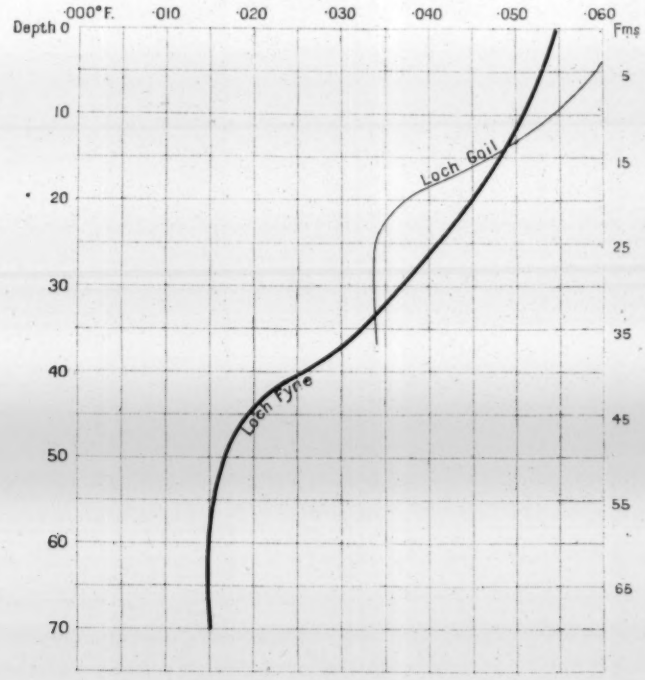


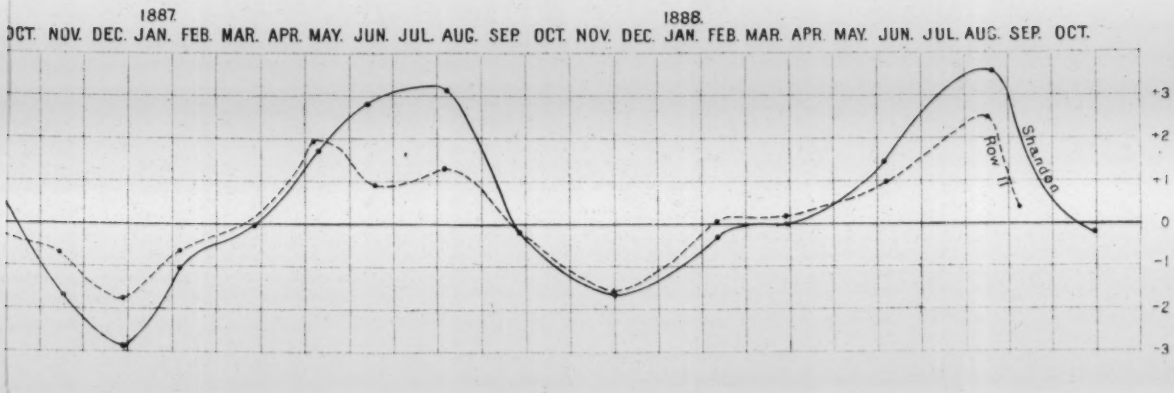
Fig. 43. **Rate of Change of Temperature at Various Depths in Loch Fyne and Loch Goil.**

dation of Annual Maximum with depth.





g. 44. **Seasonal Change of Slope in Gareloch Temperature Curves.**



TEMPERATURE CURVES

Fig. 45.
Transverse Section of Gareloch at Clynder.

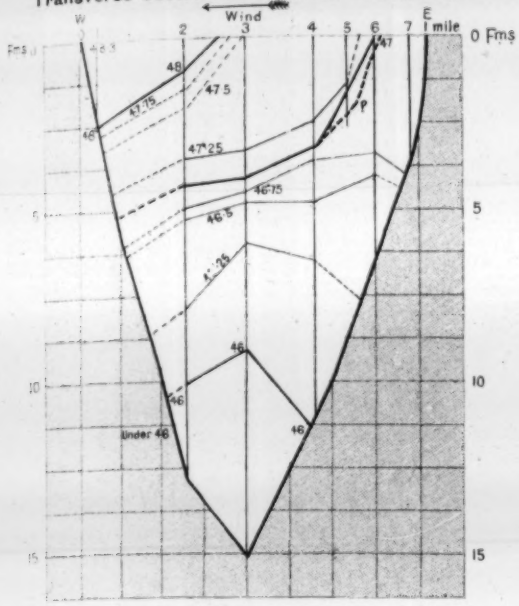


Fig. 46. **GARELOCH—Vertical Curves at Row and Si**

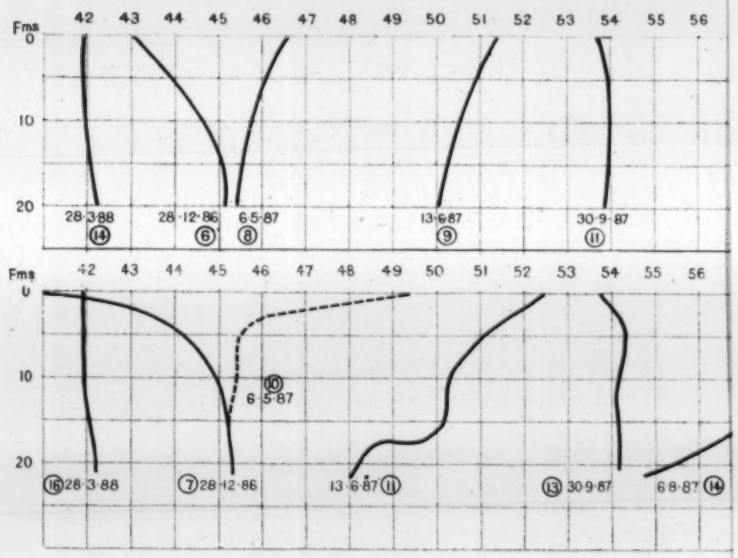


Fig. 47. **GAPELOCH—Seasonal Variation of Temperature of Water and Air.**

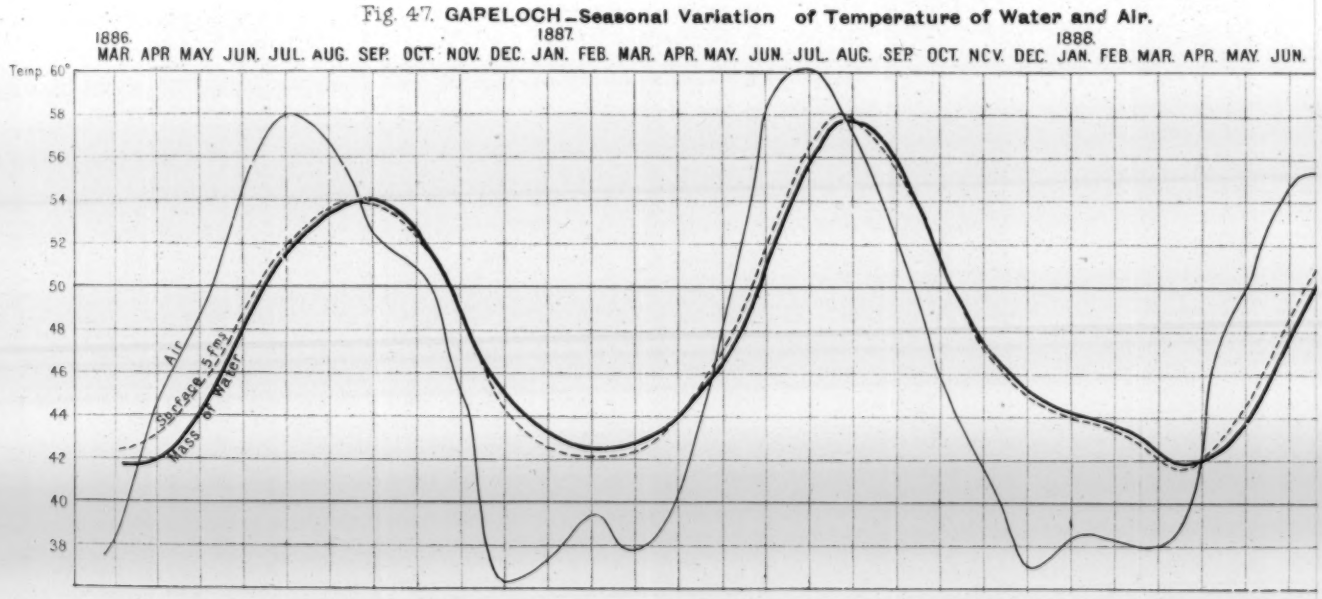
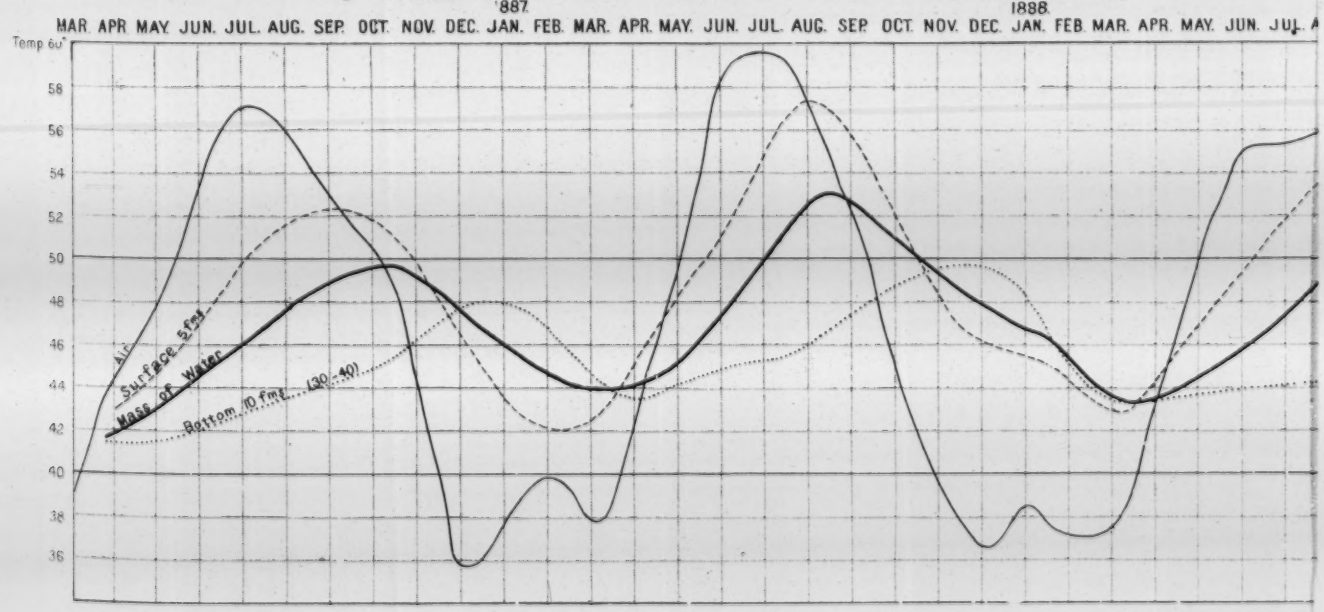


Fig. 48. **LOCH GOIL—Seasonal Variations of Temperature of Water and Air.**



TEMPERATURE CURVES

ynder.

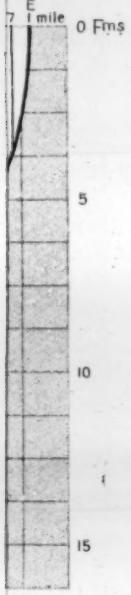


Fig. 46. GARELOCH.—Vertical Curves at Row and Shandon.

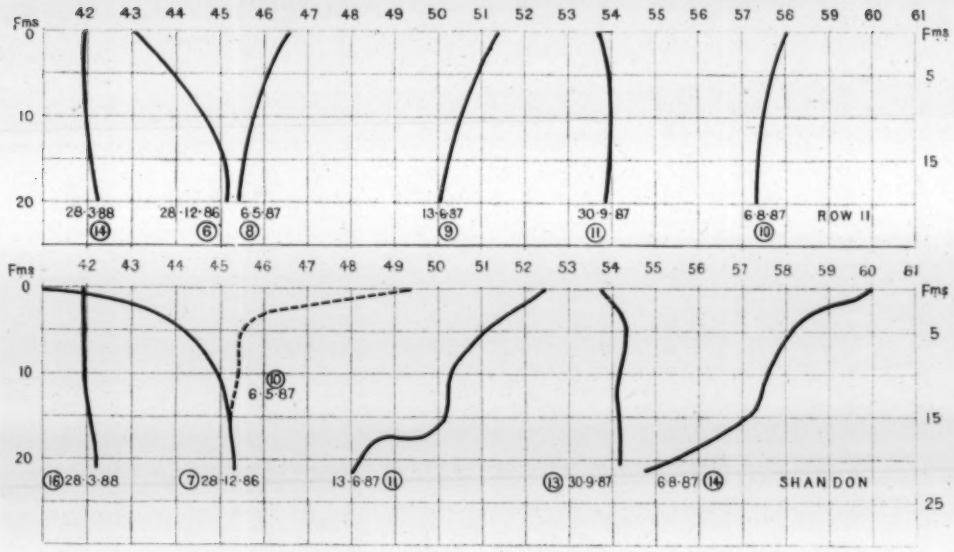
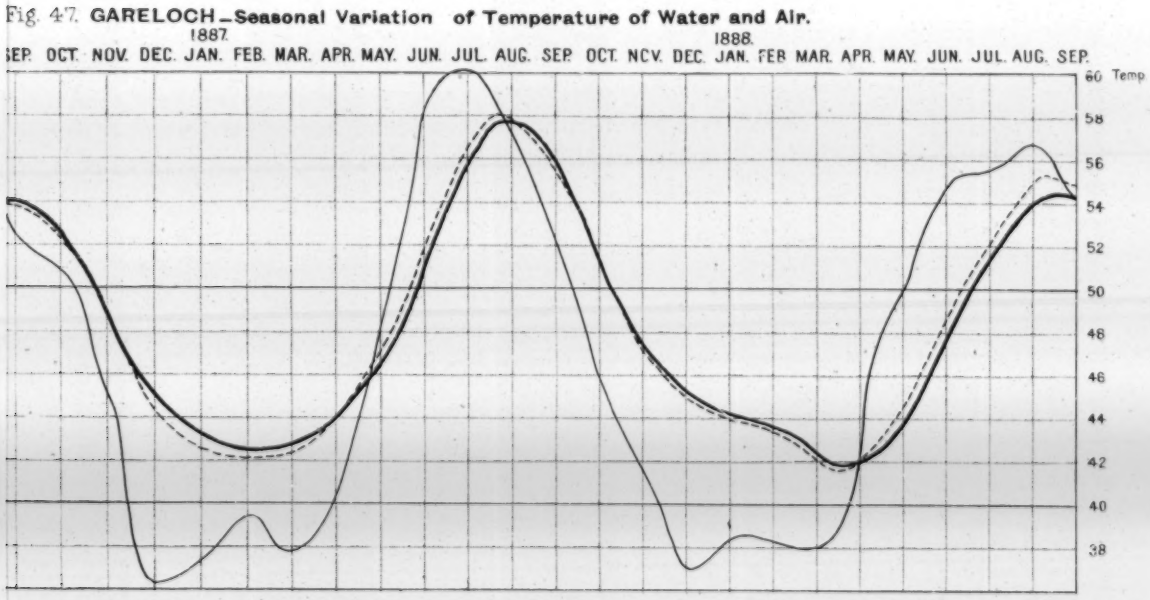
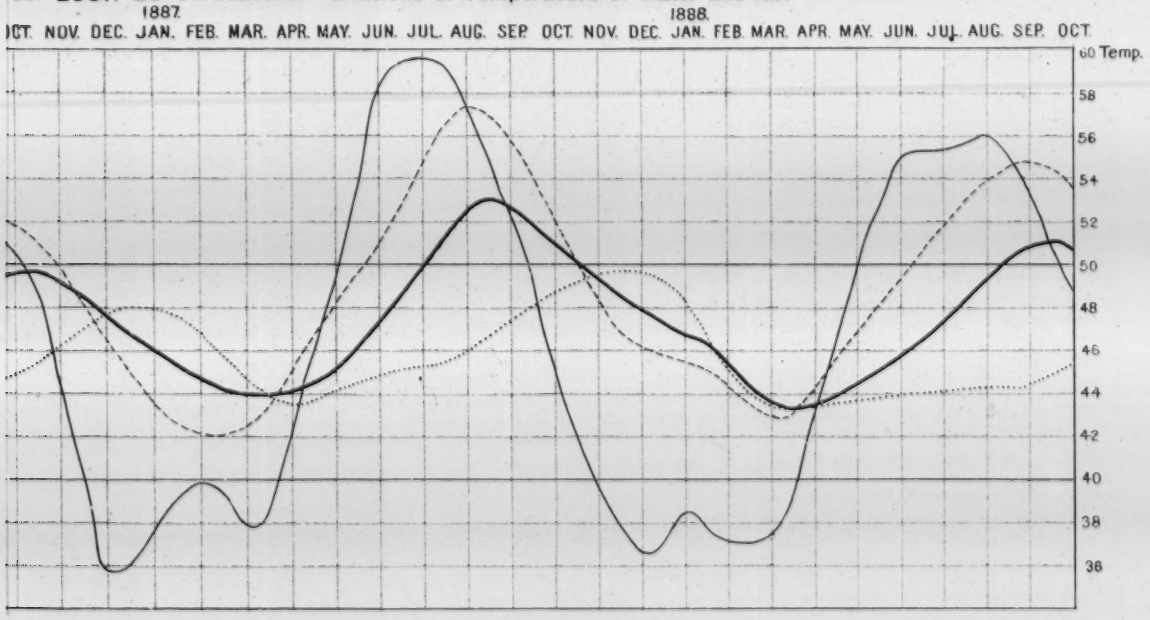


Fig. 47. GARELOCH.—Seasonal Variation of Temperature of Water and Air.



48. LOCH GOIL.—Seasonal Variations of Temperature of Water and Air.



TEMPERATURE CURVES

Fig. 49 **LOCH STRIVAN.—Seasonal Variations of Temperature of Water and Air.**

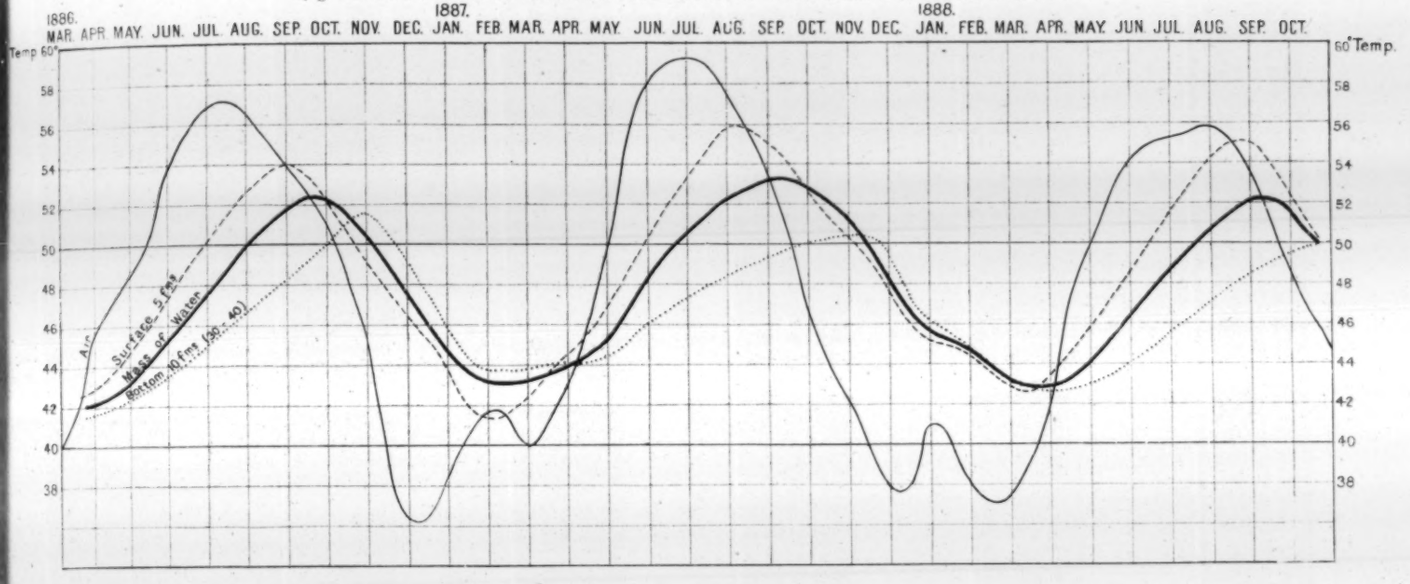
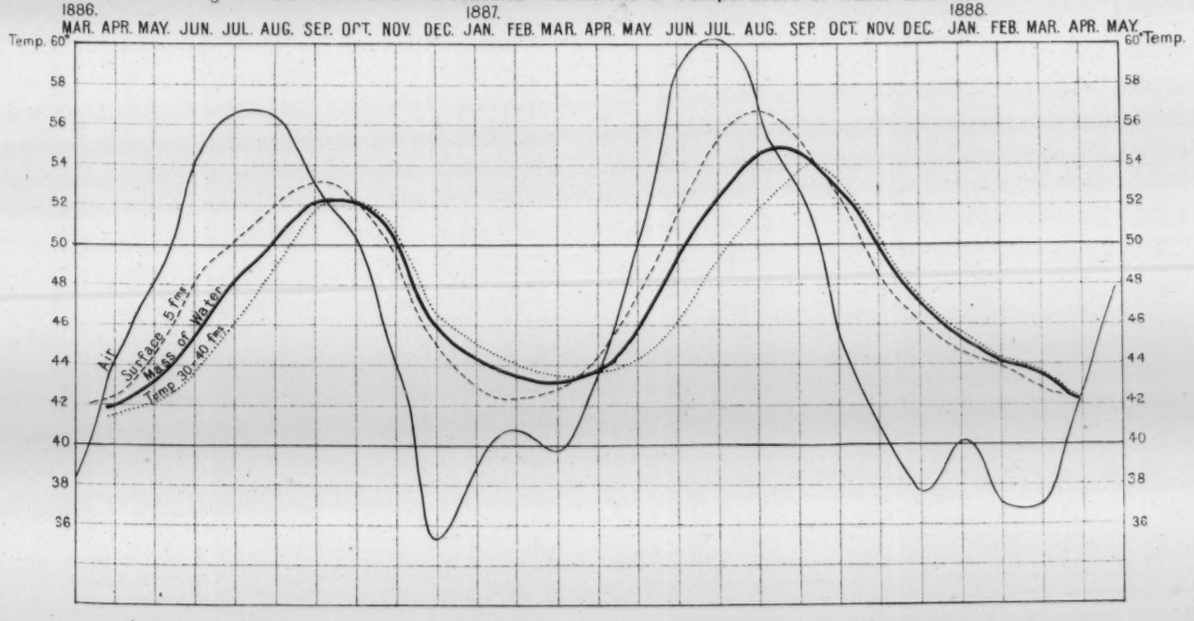


Fig. 50. **DUNOON BASIN.—Seasonal Variations of Temperature of Water and Air.**



II.—*A Fundamental Theorem regarding the Equivalence of Systems of Ordinary Linear Differential Equations, and its Application to the Determination of the Order and the Systematic Solution of a Determinate System of such Equations.*

By GEORGE CHRYSTAL, M.A., LL.D., Professor of Mathematics in the University of Edinburgh.

(Read 18th February 1895.)

Systems of ordinary linear differential equations are of great importance, both from a practical and from a theoretical point of view. They figure largely in dynamical problems; and JACOBI has shown that the general problem of determining the order of any system of ordinary differential equations whatever can be reduced to the problem of determining the order of a linear system with constant coefficients. Nevertheless, the present state of the theory of such a system still leaves something to be desired. It is true that a logical and systematic process for the solution was given by CAUCHY. This consists in first replacing the system by another in which only first differential coefficients occur, by introducing as auxiliary variables the successive differential coefficients of the various dependent variables up to the highest but one, and then reducing this system to the "normal form" by calculating the differential coefficients as linear functions of the dependent variables. It happens, however, when we attempt to do this, that we are led to a system consisting partly of differential equations of the form

$$\frac{dx_r}{dt}=f_r(x_1, \ldots, x_s)+g_r(t) \quad r=1, 2, \ldots, s. \quad . \quad . \quad . \quad (1),$$

where f_r denotes a linear function of $x_1, \ldots, x_s$, partly of a number of *non-differential equations* connecting the remainder of the variables with $x_1, \ldots, x_s$. The order of the system—that is to say, the number of independent arbitrary constants required for its complete solution—is the number of differential equations in the normal form; but no rule is readily deducible from the method for determining beforehand how many of the equations in the normal system will be differential equations, so that we cannot predict the order of the system without actually going through the labour of reduction. Moreover, the normal form is in practice often not the most convenient for the purposes of solution.

Another method, the one which is probably more familiar to English mathematicians, consists in using what may be called the "characteristic equation" of the system. For example, let x, y, z be the dependent variables and t the independent variable, and let the system be

$$\left.\begin{aligned} f_1(\mathrm{D})\,x+g_1(\mathrm{D})\,y+h_1(\mathrm{D})\,z=0 \\ f_2(\mathrm{D})\,x+g_2(\mathrm{D})\,y+h_2(\mathrm{D})\,z=0 \\ f_3(\mathrm{D})\,x+g_3(\mathrm{D})\,y+h_3(\mathrm{D})\,z=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (1)$$

where D stands for d/dt, and f_1, f_2, etc., are integral functions of D with constant coefficients. Then the conclusion is drawn from (1) that

$$\mathrm{K}x=0, \quad \mathrm{K}y=0, \quad \mathrm{K}z=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

where K is the determinant $|f_1(\mathrm{D}), g_2(\mathrm{D}), h_3(\mathrm{D})|$; so that each of the variables satisfies the differential equation

$$\mathrm{K}\xi=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3),$$

which we call the "characteristic equation" of the system, K being the "characteristic determinant." The system (2), however, is not equivalent to (1). Hence, if

$$\xi=\mathrm{A}_1 e^{\lambda_1 t}+ \ldots . +\mathrm{A}_n e^{\lambda_n t}$$

be the solution of (3), (n being the order of that equation, and therefore the degree in D of the integral function K), it does not follow that

$$x=\sum_1^n \mathrm{A}_n e^{\lambda_n t}, \quad y=\sum_1^n \mathrm{B}_n e^{\lambda_n t}, \quad z=\sum_1^n \mathrm{C}_n e^{\lambda_n t},$$

containing $3n$ arbitrary constants in all, is the solution of (2). To get rid of the superfluous constants the values of x, y, z are substituted in (1), and we thus get a set of equations of the form

$$\left.\begin{aligned} f_1(\lambda_1)\,\mathrm{A}_1+g_1(\lambda_1)\,\mathrm{B}_1+h_1(\lambda_1)\,\mathrm{C}_1=0 \\ f_2(\lambda_1)\,\mathrm{A}_1+g_2(\lambda_1)\,\mathrm{B}_1+h_2(\lambda_1)\,\mathrm{C}_1=0 \\ f_3(\lambda_1)\,\mathrm{A}_1+g_3(\lambda_1)\,\mathrm{B}_1+h_3(\lambda_1)\,\mathrm{C}_1=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (4).$$

&c.

Since λ is a root of the equation $\mathrm{K}_\lambda=0$, obtained by substituting λ for D in K, the equations (4) are equivalent to any two of them. If these two be independent, and neither of them identical as regards A_1, B_1, C_1, the ratios of A_1, B_1, C_1 are determined: and, on the like assumptions for $\lambda_2, \ldots ., \lambda_n$, the $3n$ arbitrary constants reduce to n. Even if all the assumptions made were generally true, this process could scarcely be said to be a very satisfactory proof that the order of the system is really n. In point of fact, however, as is well known, the assumptions made are not always true; and, in particular cases, the equations (4) do not in fact determine the ratios of A_1, B_1, C_1. It is true that there are various ways in which the solution may be amended in particular cases, but no general process, so far as I am aware, has been given which amounts to a proof of the theorem that *the order of the system is always the same as the order of the characteristic differential equation*, i.e., *the degree of the characteristic determinant.* In his remarkable memoir, "De investigando ordine systematis aequationum differentialium vulgarium cujuscunque" (*Crelle's Jour.* lx. 1865), JACOBI makes this theorem his starting-point; but the proof which he gives begs the question, for it amounts to nothing more than what has just been sketched for the case of three dependent variables.

The theorem in question is true; but the difficulty in demonstrating it lies in the fact that although each of the variables satisfies the characteristic equation, all of them may not be general integrals of that equation. In fact, it may happen that no one of them is a general integral. This may be seen at once by supposing the integral system of (1) to have the form $x=f(b, c, t)$, $y=g(c, a, t)$, $z=h(a, b, t)$, where a, b, c are arbitrary constants. In this case the order of the characteristic equation is 3; but the order of the differential equations which determine the separate variables is in each case 2.

I propose in this communication to give a rigorous proof of the general theorem above referred to, by means of a simple theorem regarding the equivalence of systems of linear differential equations with constant coefficients, and to deduce a systematic method for solving determinate systems of this kind which does not introduce superfluous arbitrary constants, and is not subject to failure in particular cases.

Necessary and Sufficient Condition that two Systems of Linear Equations with Constant Coefficients be equivalent.

Let the dependent variables be $x_1, \ldots, x_n$, the independent variable t, and let U_r and V_r be expressions of the form,

$$(r, 1)\, x_1+(r, 2)x_2+.-+(r, n)x_n+S_r,$$
$$[r, 1]\, x_1+[r, 2]x_2+.-+[r, n]x_n+T_r,$$

where $(r, 1) \ldots (r, n)$, $[r, 1], \ldots, [r, n]$ are integral functions of D $(=d/dt)$ with constant coefficients, and S_r and T_r are functions of t alone.

Consider any original system of m independent equations $(m \not> n)$.

$$U_1=0, \ldots, U_m=0 \quad \ldots\ldots (5).$$

Let

$$V_1=0, \ldots, V_m=0 \quad \ldots\ldots (6)$$

be a system of m independent equations "derived from" (5)—that is to say, possessing the property that every solution of (5) is a solution of (6).

Since the derived system is linear with constant coefficients as well as the original one, any process of derivation must consist in operating on the equations of the original system with integral powers of D, multiplying the resulting equations thus obtained by constants and adding. Hence we must have

$$\begin{aligned} V_1 &\equiv \xi_1 U_1 + \ldots + \xi_m U_m \\ V_2 &\equiv \eta_1 U_1 + \ldots + \eta_m U_m \quad \ldots\ldots (7) \\ &\cdots\cdots \\ V_m &\equiv \kappa_1 U_1 + \ldots + \kappa_m U_m \end{aligned}$$

where $\xi_1, \ldots, \xi_m, \ldots, \kappa_1, \ldots, \kappa_m$ are integral functions of D with constant coefficients. We may speak of these as the *multiplier-system* which derives (6) from (5); and call the determinant

$$\Delta = | \xi_1 \eta_2 \ldots\ldots \kappa_m | \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

the *modulus of the system* (6) *with respect to* (5).

We shall prove that *the necessary and sufficient condition that the system* (6) *be equivalent to* (5) *is that the modulus of* (6) *with respect to* (5) *be constant.*

In the first place, the condition is sufficient; for, if

$$| \Xi_1 H_2 \ldots\ldots K_m |$$

be the reciprocal of the determinant Δ, we have from (7)

$$\begin{aligned} \Delta U_1 &\equiv \Xi_1 V_1 + H_1 V_2 + \ldots + K_1 V_m \\ &\ldots\ldots\ldots\ldots \\ \Delta U_m &\equiv \Xi_m V_1 + H_m V_2 + \ldots + K_m V_m. \end{aligned}$$

Hence any solution of (6) satisfies

$$\Delta U_1 = 0, \ldots\ldots\ldots, \Delta U_m = 0.$$

But, if Δ reduce to a constant, this last system is equivalent to (5), for Δ cannot vanish since the system (6) consists of m *independent* equations. The condition is also necessary; for, if the system (5) be a derivative of (6), then there must exist a set of integral functions of D with constant coefficients, say $\xi_1', \ldots\ldots, \xi_m', \ldots\ldots\ldots, \kappa_1', \ldots\ldots, \kappa_m'$, such that

$$\begin{aligned} U_1 &\equiv \xi_1' V_1 + \xi_2' V_2 + \ldots\ldots + \xi_m' V_m \quad . \quad . \quad . \quad . \quad . \quad (9). \\ &\ldots\ldots\ldots\ldots \\ U_m &= \kappa_1' V_1 + \kappa_2' V_2 + \ldots\ldots + \kappa_m' V_m. \end{aligned}$$

If we substitute the values of $U_1, \ldots\ldots, U_m$ from (9) in the identities (7), then, since $U_1, \ldots\ldots, U_m$ are independent, we must have

$$\begin{aligned} &\xi_1'\xi_1 + \xi_2'\eta_1 + \ldots\ldots + \xi_m'\kappa_1 = 1 \\ &\xi_1'\xi_2 + \xi_2'\eta_2 + \ldots\ldots + \xi_m'\kappa_2 = 0 \\ &\ldots\ldots\ldots\ldots \\ &\xi_1'\xi_m + \xi_2'\eta_m + \ldots\ldots + \xi_m'\kappa_m = 0; \\ &\eta_1'\xi_1 + \eta_2'\eta_1 + \ldots\ldots + \eta_m'\kappa_1 = 0 \\ &\eta_1'\xi_2 + \eta_2'\eta_2 + \ldots\ldots + \eta_m'\kappa_2 = 1 \\ &\ldots\ldots\ldots\ldots \\ &\eta_1'\xi_m + \eta_2'\eta_m + \ldots\ldots + \eta_m'\kappa_m = 0 \end{aligned}$$

&c. &c.

Solving the above systems we have

$$\begin{aligned} &\xi_1' = \Xi_1/\Delta, \xi_2' = H_1/\Delta, \ldots\ldots\ldots, \xi_m' = K_1/\Delta \\ &\ldots\ldots\ldots\ldots \\ &\kappa_1' = \Xi_m/\Delta, \kappa_2' = H_m/\Delta, \ldots\ldots, \kappa_m' = K_m/\Delta \end{aligned}$$

Hence

$$\Delta' = |\xi_1'\eta_2' \ldots\ldots \kappa_m'| = |\Xi_1 H_1 \ldots\ldots K_m| / \Delta^m = \Delta^{m-1}/\Delta^m = 1/\Delta$$

Now, since $\xi_1', \ldots\ldots\ldots, \kappa_m'$ are all integral functions of D, Δ' must be an integral function of D, and therefore also $1/\Delta$; but this is impossible unless Δ reduce to a constant. Hence the condition is not only sufficient but necessary; and we have now the theorem in the form—

When two systems of linear equations with constant coefficients are equivalent, the modulus of either with respect to the other must be constant, and the converse is also true.

This equivalence theorem can be expressed in another form, which is convenient for some purposes.

The matrix

$$\left\| \begin{matrix} (11)\,(12) \ldots\ldots (1n) \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ (m1)\,(m2) \ldots\ldots (mn) \end{matrix} \right\| \quad \ldots\ldots\ldots \quad (10),$$

whose m rows are made up of the operator coefficients of the dependent variables in the m equations of a system, may be called the *Matrix of the System.*

From (7) we have

$$\begin{aligned} [11] &= (11)\xi_1 + (21)\xi_2 + \ldots\ldots + (m1)\xi_m \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ [1n] &= (1n)\xi_1 + (2n)\xi_2 + \ldots\ldots + (mn)\xi_m \\ \\ [21] &= (11)\eta_1 + (21)\eta_2 + \ldots\ldots + (m1)\eta_m \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ [2n] &= (1n)\eta_1 + (2n)\eta_2 + \ldots\ldots + (mn)\eta_m \\ &\quad \&c., \qquad\qquad\qquad \&c. \end{aligned}$$

Hence we have

$$\left\| \begin{matrix} [11] \ldots\ldots [1n] \\ \cdot \quad \cdot \quad \cdot \quad \cdot \\ [m1] \ldots\ldots [mn] \end{matrix} \right\| = \Delta \left\| \begin{matrix} (11) \ldots\ldots (1n) \\ \cdot \quad \cdot \quad \cdot \quad \cdot \\ (m1) \ldots\ldots (mn) \end{matrix} \right\| \quad \ldots \quad (11)$$

in the sense that every determinant in the first matrix is equal to the corresponding determinant in the second, multiplied by Δ. Hence

The necessary and sufficient condition that two systems of linear equations with constant coefficients be equivalent, is that every determinant in the matrix of the one system differs by the same constant multiplier from the corresponding determinant in the matrix of the other.

In particular,

In order that two determinate systems (of n *equations in* n *dependent variables) be equivalent it is necessary and sufficient that the determinants of the two systems differ merely by a constant factor—that is to say, that*

$$|\,(11)\,(22) \ldots\ldots (nn)\,| = |\,[11][22] \ldots\ldots [nn]\,| \times \text{const.}$$

This second form of the equivalence theorem enables us to test the equivalence of the systems directly, without calculating the system of multipliers.

Reduction of any Determinate System of Linear Equations with Constant Coefficients to an equivalent Diagonal System.

By a diagonal system is meant a system of the form

$$\begin{aligned}
[11]x_1+[12]x_2+[13]x_3+ \ldots\ldots +[1n]x_n+\mathrm{T}_1&=0\\
[22]x_2+[23]x_3+ \ldots\ldots +[2n]x_n+\mathrm{T}_2&=0\\
[33]x_3+ \ldots\ldots +[3n]x_n+\mathrm{T}_3&=0\\
\cdot\quad\cdot\quad\cdot\quad\cdot&\\
[nn]x_n+\mathrm{T}_n&=0 \quad . \quad . \quad . \quad (12),
\end{aligned}$$

where the first equation may contain all the dependent variables; the second does not contain x_1; the third does not contain x_1 and x_2; and so on, the last containing only one dependent variable, say x_n. A diagonal system is characterised by the order of the variables in the diagonal, and there are as many diagonal systems as there are linear permutations of $x_1, \ldots, x_n$. We shall see presently that the coefficients [11], [22], . . . [nn] are determined to a constant factor when the "*diagonal order*" of the variable is given. We shall speak of them as the *diagonal coefficients.* We shall now shew that

Every determinate system of linear equations with constant coefficients can be reduced to an equivalent diagonal system in which the dependent variables have any assigned diagonal order.

In the first place, we prove that

From any two equations

$$\mathrm{U}_1\equiv(11)x_1+(12)x_2+ \ldots\ldots +(1n)x_n+\mathrm{S}_1=0 \quad . \quad . \quad . \quad (13)$$
$$\mathrm{U}_2\equiv(21)x_1+(22)x_2+ \ldots\ldots +(2n)x_n+\mathrm{S}_2=0 \quad . \quad . \quad . \quad (14)$$

we can always deduce an equivalent pair, one of which does not contain any assigned dependent variable, say x_1.

For the equations

$$\mathrm{L}\,\mathrm{U}_1+\mathrm{M}\,\mathrm{U}_2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$
$$\mathrm{L}'\mathrm{U}_1+\mathrm{M}'\mathrm{U}_2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where L, M, L′, M′ are any integral functions of D with constant coefficients, will be equivalent to (13) and (14), provided the modulus of (15) and (16) with respect to (13) and (14) be constant—that is, provided

$$\mathrm{LM}'-\mathrm{L}'\mathrm{M}=\text{const.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (17).$$

Now, if g be the G.C.M. with respect to D of (11) and (21); so that

$$(11)=g(11)', \ (21)=g(21)',$$

where $(11)'$ and $(21)'$ are integral functions of D, which are prime with respect to D, and we take

$$\ldots \quad L=(21)', \quad M=-(11)',$$

then, by a well-known theorem (see my *Algebra*, vol. i. chap. vi. § 11) we can always determine two integral functions of D, L′ and M′, such that

$$(21)M'+(11)L'=\text{const.}$$

If L, M, L′, M′ be thus determined, the coefficient of x_1 in (15) will vanish, and the condition (17) will be satisfied. Hence our first preparatory theorem is established.

We next prove that

A determinate system of linear equations with constant coefficients can always be replaced by an equivalent system in which any given variable, say x_1, *occurs in only one of the equations.*

Let the system be

$$\begin{aligned} U_1 &\equiv (11)x_1+ \ldots\ldots +(1n)x_n+S_1=0 \quad \ldots \quad (18)\\ &\cdots\cdots\cdots\cdots\cdots\cdots\\ U_n &\equiv (n1)x_1+ \ldots\ldots +(nn)x_n+S_n=0. \end{aligned}$$

If any of the equations already do not contain x_1, set them aside and consider those that do contain x_1, say the first r. By our last theorem, we can replace $U_1=0$, $U_2=0$ by an equivalent pair, $U_1'=0$, $U_2'=0$, one at least of which does not contain x_1. Set that equation, say $U_1'=0$, aside along with the others that do not contain x_1. If $U_2'=0$ happens not to contain x_1, set it aside also: if not, take it along with the remaining $r-2$ equations. We thus have a system of $r-1$ equations, with which we can deal as before. By continuing this process we shall finally arrive at a single equation which must contain x_1, since the original system is determinate. This last equation, conjoined with the $n-1$ equations set aside in the above process, constitute a system equivalent to (18), only one equation in which contains x_1.

The possibility of reducing any given system (18) to a diagonal system is now obvious. We arrange the dependent variables in any order, say $x_1, x_2, x_3, \ldots, x_n$; then deduce from (18) an equivalent system only one equation, say the first, of which contains x_1. The remaining $n-1$ equations form a determinate system for $x_2, x_3, \ldots, x_n$. From this last deduce an equivalent system the first equation of which alone contains x_2; and so on. We thus arrive finally at a diagonal system, such as (12).

Properties of a Diagonal System.

It is immediately obvious that the determinant of a diagonal system reduces to the product of the diagonal coefficients. Hence by the second form of our equivalence theorem it follows that

The product of the diagonal coefficients of any diagonal system is, to a constant

factor, equal to the determinant of any system to which it is equivalent; or, in our notation,

$$|(11)(22)\ldots(nn)| = [11][22]\ldots[nn] \quad . \quad . \quad . \quad (19).$$

Every diagonal system may be solved by means of a series of linear differential equations with constant coefficients each involving only a single dependent variable. For we have merely to solve the last equation of (12) to get the complete value of x_n; then, x_n being known, the second-last will give the complete value of x_{n-1}; and so on. It will be observed that all the arbitrary constants in the expression for x_n (ω_n in number, where ω_n is the degree in D of the coefficient $[nn]$) are introduced at once. In finding x_{n-1} we introduce ω_{n-1} fresh arbitrary constants, where ω_{n-1} is the degree in D of $[n-1, n-1]$. These ω_{n-1} arbitrary constants are the arbitrary constants which occur in the expression for x_{n-1}, but not in the expression for x_n. In addition to these, x_{n-1} may contain all or some of the arbitrary constants already introduced into the expression for x_n.

Next, we find x_{n-2} by means of a differential equation of degree, ω_{n-2}, x_{n-2} will therefore contain ω_{n-2} new arbitrary constants, together with all or some of those introduced into x_{n-1} and x_n. And so on.

The whole number of arbitrary constants introduced, none of them superfluous, in the complete solution of the system is $\omega_1+\omega_2+\ldots+\omega_n$, that is the degree in D of $[11][22]\ldots\ldots[nn]$. Hence from (19) we have a rigorous proof of the general theorem referred to in the beginning of this communication, viz. :—

The order of any determinate system of ordinary linear differential equations with constant coefficients is equal to the degree in D *of its characteristic determinant.* It is obvious that *the equivalence of a diagonal system is not affected by adding to any equation* $U_r=0$ *of the system any linear combination* $L_{r-1}U_{r-1}+\ldots+L_nU_n=0$ (*where* L_{r-1}, &c., *are integral functions of* D *with constant coefficients*) *of all the equations that follow it.* For the diagonal coefficient of the resulting equation $U_r+L_{r-1}U_{r-1}+\ldots+L_nU_n=0$ remains unaltered, and it alone appears in $[11]\ldots\ldots[nn]$, the determinant of the system. Advantage of this may be taken to simplify calculations in the practical solution of a diagonal system. Into the question as to the maximum of simplification thus attainable I shall not enter; but it appears from the above remark that the coefficients of a diagonal system, other than the diagonal coefficients, are not uniquely determined when the diagonal order of the dependent variables is assigned.

It is easy, however, to show that *the diagonal coefficient of any variable is determined when the aggregate of the variables that follow it in the diagonal order is given.* For let x_r be the variable in question, $x_{r-1}, x_{r-2}, \ldots\ldots, x_n$ those that follow it in any given order, and let the corresponding diagonal coefficients be $[rr], [r-1, r-1], \ldots\ldots, [n, n]$: and let the corresponding coefficient in the case where x_r again stands first, but $x_{r-1}, x_{r-2}, \ldots, x_n$ are arranged in any other order be $[rr]', [r-1, r-1]', \ldots\ldots [nn]'$. Since the last r equations form by themselves in the two cases a pair of equivalent determinate systems for $x_r, x_{r-1}, \ldots\ldots\ldots, x_n$, we must have

$$[rr][r-1, r-1] \ldots\ldots [nn]=[rr]'[r-1, r-1]' \ldots\ldots [nn]' \quad . \quad . \quad (20)$$

by the second equivalence theorem. Again, the last $r-1$ equations in the two cases form a pair of equivalent determinate systems for $x_{r-1}, x_{r-2}, \ldots\ldots, x_n$: hence

$$[r-1, r-1] \ldots\ldots [nn]=[r-1, r-1]' \ldots\ldots [nn]' \quad . \quad . \quad (21).$$

Now, from (20) and (21) we have $[rr]=[r, r]'$, which proves our theorem.

It is obvious, alike from considerations already detailed regarding the successive introduction of the arbitrary constants, and from the possible derivations by means of which we can deduce from a given diagonal system an equivalent one with a different diagonal order of the variables, that *the diagonal coefficient for any given variable is of least degree in* D *when it is first, and of greatest degree when it is last in the diagonal order; and that promotion in the diagonal order may increase but cannot diminish the degree of the diagonal coefficient.*

The diagonal coefficients in the two extreme cases are of greatest importance; because the degree of the diagonal coefficient, when the variable is last in the diagonal order, is the whole number of arbitrary constants in the complete expression for the dependent variable in question; and the degree, when it is first, in the number of arbitrary constants which occur in the expression for that variable and do not occur in the expression for any of the others. We are thus led to investigate rules for calculating the first and last of the diagonal coefficients for any given order of the dependent variables, say $x_1, x_2, \ldots\ldots, x_n$. Let

$$\begin{vmatrix} \xi_1, \ldots\ldots, \xi_n \\ \ldots\ldots\ldots \\ \kappa_1, \ldots\ldots, \kappa_n \end{vmatrix} \quad \begin{vmatrix} \xi_1', \ldots\ldots, \xi_n' \\ \ldots\ldots\ldots \\ \kappa_1', \ldots\ldots, \kappa_n' \end{vmatrix}$$

be the systems of multipliers of (12) with respect to (18), and of (18) with respect to (12), where, since the systems are equivalent, all the multipliers must be integral functions of D. Then we have, *inter alia*,

$$[11]\,\xi_1'=(11), \quad [11]\,\eta_1'=(21), \ldots\ldots, [11]\,\kappa_1'=(n1) \quad . \quad . \quad . \quad (22)$$

$$(11)\,\xi_1+(21)\,\xi_2+\ldots+(n1)\,\xi_n=[11] \quad . \quad . \quad . \quad . \quad (23)$$

From (22) it follows that [11] must be a common divisor of (11), (21), ..., (n1); and from (23) that the G.C.M. of (11), (21), ..., (n1) must divide [11] exactly. *Hence* [11] *must, to a constant factor, be simply the G.C.M. of* (11), (21), ..., (n1), y_1 *say.*

Again, the complete system for determining $\kappa_1, \ldots\ldots, \kappa_n$ is

$$\left.\begin{aligned} &(11)\kappa_1+(21)\kappa_2+\ldots+(n1)\kappa_n=0 \\ &\quad\ldots\ldots\ldots\ldots\ldots \\ &(1, n-1)\kappa_1+(2, n-1)\kappa_2+\ldots+(n, n-1)\kappa_n=0 \\ &(1n)\kappa_1+(2n)\kappa_2+\ldots+(nn)\kappa_n=[nn] \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (24).$$

If therefore

$$|\{11\}\{22\}.....\{nn\}| \quad . \quad . \quad . \quad . \quad . \quad (25)$$

denote the reciprocal matrix to $|(11)(22).....(nn)|$, we have from the first $n-1$ equations of (24)

$$\kappa_1 : \kappa_2 : ..... : \kappa_n = \{1n\}' : \{2n\}' : .... \{nn\}',$$

where $\{1n\}', ... \{nn\}'$ are the set of relatively prime integral functions of D which arise by dividing $\{1n\} ..... \{nn\}$ by their G.C.M., G_n say. Therefore

$$\kappa_1 = \lambda\{1n\}', \ \kappa_2 = \lambda\{2n\}', ..., \ \kappa_n = \lambda\{nn\}',$$

where λ is some integral function of D, or a constant.

Now, since $|\xi_1\eta_2 ..... \kappa_n|$ must be constant, (12) and (18) being equivalent, it follows that λ must be a constant; for $|\xi_1 n_2 ..... \kappa_n|$ obviously contains the factor λ. We must therefore have

$$[nn] = \lambda[(1n)\{1n\}' + (2n)\{2n\}' + ... + (nn)\{nn\}'] = \lambda\,|(11)(22)...nn|/G_n \ . \quad (26),$$

that is to say, *we must have, to a constant factor,* $[nn] = K/G_n$, *where* K *is the characteristic determinant of the original system.*

We are thus led to the following general rule:—

Form the schemes

	x_1	x_2	.....	x_n	
U_1	(11)	(12)	.....	(1n)	
U_2	(21)	(22)	.....	(2n)	
⋮	.	.	.	.	. . . . . (27),
U_n	(n1)	(n2)	.....	(nn)	
	g_1	g_2	.....	g_n	

and

	x_1	x_2	.....	x_n	
	{11}	{12}	.....	{1n}	
	{21}	{22}	.....	{nn}	
	.	.	.	.	. . . . . (28),
	{n1}	{n2}	.....	{nn}	
	G_1	G_2	.....	G_n	

by means of the matrix of the given system and its reciprocal matrix, $g_1, g_2, ..., g_n$, *and* $G_1, G_2, ..., G_n$ *being the G.C.M.s of the constituents of the respective columns, then*

$$\left.\begin{matrix} g_1, & g_2, & ....., & g_n; \\ K/G_1, & K/G_2, & ....., & K/G_n \end{matrix}\right\} \ . \quad . \quad . \quad . \quad . \quad (29)$$

are the diagonal coefficients of the variables $x_1, x_2, ..., x_n$ *when these are first and last in diagonal order respectively.*

And, further, the differential equations for determining the variables separately are (*since* $V_n \equiv K_1U_1 + \ldots + K_nU_n$)

$$\left.\begin{aligned} \frac{K}{G_1}x_1 + \frac{\{11\}}{G_1}S_1 + \frac{\{21\}}{G_1}S_2 + \ldots\ldots + \frac{\{n1\}}{G_1}S_n = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \frac{K}{G_n}x_n + \frac{\{1n\}}{G_n}S_1 + \frac{\{2n\}}{G_n}S_2 + \ldots\ldots + \frac{\{nn\}}{G_n}S_n = 0 \end{aligned}\right\} \quad \ldots \quad (30).$$

In other words, these are the last equations in diagonal systems when $x_1, \ldots\ldots x_n$ *are last in diagonal order respectively.*

It must be noticed, however, that (30), *considered as a system*, is not equivalent to the given system, although it gives correctly each of the variables separately—that is to say, it gives correctly a value for each variable which, along with a corresponding set of properly-determined values, will constitute a solution of the system.

Conditions for the "Simplicity" of a Diagonal System.—Prime Systems.

When a diagonal system contains only one differential equation, this equation must, of course, be the last (unless it be possible to select from among the dependent variables a set of r which can be determined wholly by non-differential equations, each of which will therefore contain no arbitrary constant whatever in its expression, a case which we may suppose excluded; see Example 1, p. 175). In this case the order of the system is the order of this last differential equation. All the diagonal coefficients $[11]$, $[22]$, $\ldots\ldots$, $[n-1, n-1]$ reduce to constants, for no one can vanish in a determinate system; and the first $n-1$ equations are non-differential equations, by means of which we can calculate successively the variables in terms of those previously found, and of their differential coefficients. Such a system may be called a *Simple Diagonal System.*

There are two important criteria for the possibility of reducing a given system to a simple diagonal system.

Since in all cases we have

$$K = [nn]\,[n-1, n-1] \ldots\ldots [22]\,[11],$$

and since the operations by which $[11], \ldots\ldots, [nn]$ are derived from the coefficients of the original system are all rational, it follows that the coefficients of all these integral functions of D are rational functions of the coefficients of the original system. It follows that, if K be irreducible in the sense that it has no integral factors whose coefficients are integral functions of the coefficients in the operator-coefficients in the original system, then all the functions $[11], \ldots\ldots, [nn]$, except one (under ordinary circumstances the last), must reduce to constants, and this one will then differ by a constant factor merely from K. Hence the following important theorem:—

If K be irreducible, then every equivalent diagonal system to which a given system

can be reduced is simple. In such a case, each of the dependent variables will involve all the m arbitrary constants required by the order of the system.

Again, if in the reciprocal matrix there be any one column, say the last, which is relatively prime, then, if we take the variable x_n corresponding to that column as the last in an equivalent diagonal system, the last equation in that system will, by (30), be $Kx_n +$, &c., $= 0$—that is to say, $[nn]$ will differ from K merely by a constant factor; and therefore $[11]$, ... , $[n-1, n-1]$ must all reduce to constants. Hence

For every prime column in the reciprocal matrix of a given system a series of equivalent simple diagonal systems can be formed in which the corresponding variable is the last variable.

In particular, if every column of the reciprocal matrix be prime, then every equivalent diagonal system will be simple, and the expression for each of the dependent variables will contain all the arbitrary constants of the system.

This second criterion obviously includes the first; for, if K be irreducible, all the columns of the reciprocal matrix must be prime.

By a preliminary transformation we can always make the solution of any system depend on the solution of another system all the columns of whose characteristic determinant are prime. Such a system we may call a *prime system.* We have merely to introduce new variables $X_1, \ldots\ldots, X_n$ such that

$$g_1 x_1 = X_1, \ldots\ldots g_n x_n = X_n \quad . \quad . \quad . \quad . \quad . \quad (31).$$

Having solved the new system in $X_1, \ldots\ldots, X_n$, we pass to the solution of the original system by solving system (31), which consists merely of single equations for the separate variables.

A prime system is by no means necessarily transformable into a simple diagonal system; it has, however, the characteristic property that, in every equivalent diagonal system, the first equation is non-differential.

Practical Methods of Solution.

The foregoing theory suggests various methods for solving linear systems with constant coefficients. The most natural method, and, if a particular solution of the system cannot readily be guessed, possibly the best, is to transform the system into a prime system, and then reduce the latter to an equivalent diagonal system, simplify this last as much as possible, solve it, and then pass back to the original system.

We may also proceed step by step, as follows:—Transform to a prime system, separate one of the variables, say x_1, in this system by reducing it to an equivalent system in which x_1 occurs in only one equation. The rest of this new system is a determinate system for $x_2, \ldots\ldots, x_n$. Transform this last to a prime system, then separate one of the variables as before, and so on.

When the system has a prime reciprocal matrix, and therefore admits of being transformed into a simple diagonal system, the ordinary method of determining the arbitrary constants by substitution is convenient. This method may be employed in any case, and the work can be shortened by ascertaining from (30) what terms actually do occur in the complementary functions of the respective variables.

Other modifications suggest themselves in the light of the foregoing theory; but it seems unnecessary to pursue the matter here. Nor shall I enter into the interesting question as to how far the general principles above laid down could be extended to systems of ordinary linear equations whose coefficients are not constant.

But it may be useful to append some simple examples to illustrate some of the points of the general theory.

Example 1 :—

$$\begin{aligned}(\mathrm{D}^2+1)\,x+(\mathrm{D}^2+\mathrm{D}+1)\,y&=t,\\ \mathrm{D}\,x+\quad(\mathrm{D}+1)\,y&=e^t.\end{aligned}$$

The characteristic determinant of the system reduces to 1: we should therefore expect that the solution contains no arbitrary constants at all. In effect, if we use the multiplier-system,

$$\begin{vmatrix}1, & -\mathrm{D}\\ \mathrm{D}, & -\mathrm{D}^2-1\end{vmatrix},$$

whose determinant is constant, we deduce the equivalent system

$$\begin{aligned}x+y&=t-e^t,\\ -y&=1-2e^t,\end{aligned}$$

whence $x=1+t-3e^t$, $y=2e^t-1$.

The fact that a system of differential equations may have a general solution which involves no arbitrary constant whatever, is suggested naturally enough both by the foregoing theory and also by CAUCHY's theory of the order of any system. It has, however, been so seldom emphasised that it seemed worth while to give the present simple instance of the phenomenon in question.

Example 2 :—

$$\left.\begin{aligned}(\mathrm{D}^3-\mathrm{D}+2)x+(2\mathrm{D}-2)y&=e^{-t},\\ (-3\mathrm{D}^2-4\mathrm{D}+1)x+(\mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1)y&=0\end{aligned}\right\}\quad\ldots\quad(a).$$

Here

$$\begin{aligned}\mathrm{K}\equiv&\begin{vmatrix}\mathrm{D}^3-\mathrm{D}+2, & 2\mathrm{D}-2\\ -3\mathrm{D}^2-4\mathrm{D}+1, & \mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1\end{vmatrix}\\ &\equiv \mathrm{D}(\mathrm{D}+1)^3(\mathrm{D}^2+1).\end{aligned}$$

The reciprocal matrix—viz.,

$$\begin{vmatrix}\mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1, & 3\mathrm{D}^2+4\mathrm{D}-1\\ -2\mathrm{D}+2, & \mathrm{D}^3-\mathrm{D}+2\end{vmatrix},$$

has all its columns prime; hence any equivalent diagonal system must be simple. If we take x as the last variable, the matrix of the system of multipliers will be

$$\begin{vmatrix} \mathrm{L}, & \mathrm{M}, \\ \mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1, & -2\mathrm{D}+2 \end{vmatrix},$$

where L and M must be so determined that

$$\mathrm{L}(2\mathrm{D}-2)+\mathrm{M}(\mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1)=\text{const.}$$

The quickest method in practice for determining L and M will be understood from the following special application :—Let

$$u \equiv 2\mathrm{D}-2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\beta),$$
$$v \equiv \mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (\gamma).$$

Eliminating D^3, we get

$$\mathrm{D}^2u-2v \equiv -8\mathrm{D}^2-10\mathrm{D}+2 \quad . \quad . \quad . \quad . \quad . \quad (\delta).$$

Next, eliminating D^2 by means of (β) and (δ),

$$(\mathrm{D}^2+4\mathrm{D})u-2v \equiv -18\mathrm{D}+2 \quad . \quad . \quad . \quad . \quad . \quad (\epsilon).$$

Finally, eliminating D by means of (β) and (ϵ),

$$(\mathrm{D}^2+4\mathrm{D}+9)u-2v=-16;$$

we may therefore take $\mathrm{L} \equiv \mathrm{D}^2+4\mathrm{D}+9$ and $\mathrm{M}=-2$, so that the required multiplier-matrix is

$$\begin{vmatrix} \mathrm{D}^2+4\mathrm{D}+9, & -2 \\ \mathrm{D}^3+3\mathrm{D}^2+5\mathrm{D}-1, & -2\mathrm{D}+2 \end{vmatrix}.$$

This reduces the system (α) to

$$-16y+(\mathrm{D}^5+4\mathrm{D}^4+8\mathrm{D}^3+4\mathrm{D}^2+7\mathrm{D}+16)x=6e^{-}$$
$$\mathrm{D}(\mathrm{D}+1)^3(\mathrm{D}^2+1)x=-4e^{-t};$$

a simple system as predicted.

From this we get by the familiar methods,

$$x=\mathrm{A}+(\mathrm{B}+\mathrm{C}t+\mathrm{E}t^2)e^{-t}+\mathrm{F}\cos t+\mathrm{G}\sin t+\tfrac{1}{3}t^3e^{-t},$$

and, substituting this value in the first equation,

$$y=\mathrm{A}+\tfrac{1}{4}\{(2\mathrm{B}+3\mathrm{C}-3\mathrm{E})+(2\mathrm{C}+6\mathrm{E})t+2\mathrm{E}t^2\}e^{-t}$$
$$+\mathrm{F}\cos t+\mathrm{G}\sin t+\tfrac{1}{8}(-1-6t+6t^2+\tfrac{4}{3}t^3)e^{-t}.$$

Example 3:—

$$\left.\begin{aligned} \mathrm{D}x+\mathrm{D}y+(\mathrm{D}-1)z&=0, \\ (\mathrm{D}-1)x+\mathrm{D}^2y+(\mathrm{D}-1)^2z&=0, \\ (\mathrm{D}+1)x+\mathrm{D}^3y+(\mathrm{D}^2-1)z&=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (a).$$

If we put $\eta = Dy$, $\zeta = (D-1)z$, we reduce (α) to the prime system

$$\left.\begin{aligned} Dx \quad &+\eta \ + \ \xi \quad &=0 \\ (D-1)x+D\eta \ &+(D-1)\xi &=0 \\ (D+1)x+D^2\eta &+(D+1)\xi &=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (\beta);$$

for which

$$\begin{aligned} K \equiv &\begin{vmatrix} D & , 1 & , 1 \\ D-1, & D, & D-1 \\ D+1, & D^2, & D+1 \end{vmatrix} \\ &\equiv -D(D-1)(D^2-2D-1) \\ &\equiv -D(D-1)(D-\alpha)(D-\beta), \quad . \quad . \quad . \quad . \quad . \quad \gamma), \end{aligned}$$

where $\alpha = 1+\sqrt{2}$, $\beta = 1-\sqrt{2}$.

The reciprocal matrix is

$$\begin{vmatrix} -D^3+2D^2+D, & 0 & , & D^3-2D^2-D \\ D^2-D-1, & D^2-1 & , & -D^3+D+1 \\ -1, & -D^2+2D-1, & & D^2-D+1 \end{vmatrix} \quad . \quad . \quad . \quad (\delta),$$

the columns of which are prime, except that corresponding to η, which contains the factor $D-1$.

The system (β) is of the fourth order, and the forms in the complementary function are 1, e^t, $e^{\alpha t}$, $e^{\beta t}$, the second of which does not occur in η, owing to the presence of the factor $D-1$ in the corresponding column of (δ). Hence the solution has the form—

$$\begin{aligned} x &= a+b\,et+c\,e^{\alpha t}+d\,e^{\beta t}, \\ \eta &= f \qquad +g\,e^{\alpha t}+h\,e^{\beta t}, \\ \zeta &= k+l\,et+m\,e^{\alpha t}+n\,e^{\beta t}, \end{aligned}$$

in which the four constants a, b, c, d may be taken as the four arbitrary constants of the system (β).

By substituting the separate parts in (β), we find at once

$$f=a,\ k=-a,\ l=-b,\ g=2c,\ h=2d,\ m=-(3+\sqrt{2})c,\ n=-(3-\sqrt{2})c.$$

In the present case, since the particular integral is $x=0$, $\eta=0$, $\zeta=0$, this, which is merely a simplification of the ordinary method, is practically the quickest method of solution.

In order, however, to illustrate the general theory given above, we may give the reduction to a diagonal system.

Using the multiplier-system,

$$\begin{vmatrix} D-1, & -1 \\ D, & -1 \end{vmatrix},$$

we can replace the first two equations of (β) by two others, one not containing ζ, and thus derive

$$\left.\begin{aligned}(D^2-2D+1)\,x-\eta&=0\\(D^2-D+1)\,x+0\eta+\xi&=0\\(D+1)\,x+D^2\eta+(D+1)\,\xi&=0\end{aligned}\right\}\quad\ldots\ldots\quad(\epsilon).$$

By means of the multiplier-system,

$$\begin{vmatrix} D+1, & -1\\ D, & -1\end{vmatrix},$$

for the last two equations of (ϵ), we derive

$$\left.\begin{aligned}(D^2-2D+1)\,x-\eta&=0\\(D^3-D)\,x-D^2\eta&=0\\(D^3-D^2-1)\,x-D^2\eta-\xi&=0\end{aligned}\right\}\quad\ldots\ldots\quad(\zeta).$$

Finally, using

$$\begin{vmatrix} D^2, & -1\\ D^2+1, & -1\end{vmatrix}$$

on the first two equations of (ζ), we deduce the diagonal system

$$\begin{aligned}(D^3-D^2-1)\,x-D^2\eta-\xi&=0,\\(D^4-3D^3+2D^2-D+1)\,x-\eta&=0,\\(D^4-3D^3+D^2+D)\,x&=0,\end{aligned}$$

which, by using the last equation in the second, may be reduced to

$$\left.\begin{aligned}(D^3-D^2-1)\,x-D^2\eta-\xi&=0\\(D^2-2D+1)\,x-\eta&=0\\(D^4-3D^3+D^2+D)\,x&=0\end{aligned}\right\}\quad\ldots\ldots\quad(\eta).$$

The system (η) may now be solved very readily, and leads to the same result as before.

After solving (β) by either method, we pass back to (α) by solving the two equations

$$Dy=\eta,\ (D-1)\,z=\xi;$$

and thus get the complete solution of (α) involving six arbitrary constants.

III.—*On Bird and Beast in Ancient Symbolism.* By Professor D'Arcy Wentworth Thompson, Jr.

(Read 4th June 1894.)

The following essay, except for one or two slight corrections and additions which I have since interpolated, was read before the Royal Society of Edinburgh in June 1894. Very shortly thereafter, M. Jean Svoronos published in the *Bulletin de Correspondance Hellénique* (Janv.–Juillet, 1894) a learned paper "*Sur la signification des types monétaires des anciens*," in which he demonstrated with an elaborate wealth of illustration the astronomic significance of many coin-types, the precise point that the greater part of this essay of mine was written to prove. Beginning with coins on which a beast- or bird-emblem is figured together with the symbol of a star, and passing on to others where the star-symbol is omitted, M. Svoronos shows clearly that in a very varied series of coin-types, the Lion, the Bull, the Eagle, the Horse, and so forth, represent not merely these creatures themselves, but their stellar namesakes: in short, that, in more or less obscure and occult shapes, astronomic emblems are imprinted on a vast range of ancient coins, just as in open and acknowledged forms they are visible, for instance, on the coins of Antoninus Pius. So clearly is all this put forward by M. Svoronos that my paper might well have remained unpublished were it not that I think I take the case somewhat further than he does. For, whereas M. Svoronos is content to demonstrate the symbols of individual constellations, I have attempted also in certain cases to show that the associated emblems correspond to the positions relative to one another of the heavenly bodies, in some cases to the configuration of the sky at critical periods of the year or at the festival seasons of the cities to which the coins belong. In some other respects, also, I have attempted to carry to a further issue the general considerations suggested by the astronomic hypothesis.

In a *Glossary of Greek Birds* now passing through the press, I have indicated, so far as the scope of the work and the size of the book permit me, certain astronomical phenomena which seem to me to be veiled or symbolised in art and in literature in connection with certain bird-names. The present essay deals with the same hypothesis in greater detail, and adduces a somewhat different set of illustrations in support of it.

In Miss J. E. HARRISON's book on *The Mythology of Ancient Athens* there is to be found a learned, but, to my thinking, a mistaken explanation of the great relief of Cybele in the Hermitage Museum at St Petersburg. This monument seems to me to be capable of a far simpler and far more interesting explanation. The two annular symbols on either side of the central figure are not, to my mind, mere adjuncts of the picture, φίαλαι, or votive gifts offered to the goddess; they are the ancient symbols of the sun, as we still find them to this day in astronomical and astrological works. The figure

FIG. 1.—Cybele Relief (Hermitage Museum, St Petersburg).*

to the right of the group, with the water-jar on his shoulder, is no mere πρόσπολος or temple-server, but the Water-bearer himself; nor is the Lion "a mere lap-dog," or symbol of the dominion of the goddess. The group represents, in short, *the Sun in Leo* and *the Sun in Aquarius.*

The statement that this great monument displays two zodiacal signs would scarcely deserve credence, and the fact, if admitted, would be of comparatively small interest,

* I am indebted for the loan of this engraving to Messrs Macmillan & Co., and for that of the Lion and Bull on p. 182 to Mr John Murray; the other engravings are all the gift and handiwork of Mrs W. R. H. Valentine, Dundee.

could we not show that these two signs were in some way related to one another, and had a definite meaning in their conjunction. Now, in the first place, Leo and Aquarius are just six signs or six months apart; and, in the second place, they were, in the epoch immediately preceding that of classical astronomy, *the tropical or solstitial signs.* The sun, which had its summer and winter solstices in Cancer and Capricorn in classical times, stood in Leo and Aquarius at the corresponding seasons in the immediately preceding age; and just as we still speak of the tropics of Cancer and Capricorn, though the sun in its precessional course has now moved into Gemini and Sagittarius, so the yet older signs of Leo and Aquarius held their place in Hellenic speech and symbol when Cancer and Capricorn had superseded them in scientific astronomy and in actual fact. In a word, the monument was emblematic of the midsummer solstice, when the sun was rising in Leo and Aquarius was setting in the west; and the heavenly signs are shown circling round the head of the Earth-Mother.

While this is the simplest explanation, and the one which first occurred to me of the conjunction of the two signs, there is yet another very closely akin, which I offer as a perhaps preferable alternative. When the sun is in Leo, that is to say (at the epoch of which I speak) in the month of the summer solstice, the full moon of that month is situated in the opposite sign of Aquarius; and it is therefore conceivable, and even probable, that the monument represents the sun and moon in opposition at midsummer, that is to say, the season of the full moon in the month of Leo.

Whichever of these two closely allied interpretations of the monument we prefer, we should, in either case, expect to find the same subject repeated in other monuments and works of art, were it a type so ancient and so important as I take it to be. On the very next preceding page of Miss HARRISON'S book we find it again: the Lion sits at Cybele's feet on the left, and on the right we see the Watering-pot and hand of Aquarius, whose retreating figure has been broken away. In another of Miss HARRISON'S figures we have one-half of the same subject, the Lion lying in Cybele's lap, symbolising equally well the midsummer season. And yet again, we meet with the whole group in a certain very ancient Mithraic monument.

The frieze sculptured along the base of the St Petersburg monument is eminently corroborative of my hypothesis. It represents the ancient and widespread device of the Bull and Lion in combat, the Bull kneeling with lowered head to the left, the Lion on the right in attitude of attack. In the same epoch when Leo and Aquarius occupied the place of the solstices, the Bull marked the spring equinox, the ancient opening of the year:—"Candidus auratis aperit cum cornubus annum Taurus."

The Bull and the Lion, then, if we follow the same line of argument as we have taken in regard to the major group, represent spring and summer, spring giving way before the heats of summer; or, restricting ourselves to the face of the sky as revealed at one particular date or moment, we may interpret the victorious Lion as Leo standing in mid-heaven precisely when Taurus is setting in the west.

The conjunction of the Bull and Lion is extraordinarily frequent in art, and their combat

is an ancient simile in literature. It is hard, indeed, to believe that these allusions and representations refer to actual combat of the two animals, or to depredations on the part of the lion upon the peasant's kine. The allusion is far more subtle and more mystical. *Pace* HERODOTUS, it is hard to believe that there is the smallest proof of the existence of lions in Greece within historic times: the bull would, in any circumstances, be an animal seldom attacked by the lion; it would never be found near the haunts of the lion in Africa, and probably not very often in Assyria; and the conventional picture of the combat is stereotyped and unnatural. The stories of the Eagle attacking the Bull are scarcely more untrue to nature, and are equally mystical in their interpretation.

The following sketch, taken from a shield found at Amathus in Cyprus (CESNOLA, Cyprus, pl. xx.), where certainly lions never occurred, represents the conventional picture, which we find repeated over and over again. The Bull is to the left of the Lion; its

FIG. 2.—Lion and Bull in Combat, from a Cyprian Shield.

attitude is that of the constellation Taurus, and we note in particular its bent knee as ARATUS describes it (Phaen. 517):—

Ταύρου δὲ σκελέων ὅσση περιφαίνεται ὀκλάξ,

or in CICERO's translation:—"Atque genu flexo Taurus connititur ingens."

If we pass to the great and much-neglected store of ancient symbolism in coins and gems, we find the same subject again and again. And here, though it is not my purpose in this short essay to deal fully in argument with other views, I must make one brief digression. Professor RIDGEWAY'S now widely accepted views on the patterns of ancient coinage would, as it seems to me, give a meaning to coin-types where numismatists had none to offer before, but it is a meaning foreign to all we know of ancient symbolism. His theory that not merely the ox, but the tortoise, the fish, the silphium plant, the ear of corn, and so forth, represent articles of general or local commerce whose barter the coins replaced, is to give to the nations of antiquity a *numismatique boutiquière*, which might be paralleled in modern times were the people of Gushetneuk to stamp a red

herring on their groats. Mr RIDGEWAY'S theory is of a piece with the speculations of those who, running folk-lore to the death, seek to read antiquity in the light of savagery; who see the childhood of the world in a culminating age of astronomic science, symbolic art, and mystical religion, and who arrive at what I unhesitatingly regard as misconception by the double blunder of unduly depreciating the complexity of initial or archaic Greek thought, and unduly exalting the importance and too freely correlating the results of their own study of incipient or semibarbarous civilisations. We must see fallacy in any theory which treats as nascent and primitive the civilisation of a period of exalted poetry, the offspring of ages of antecedent culture; which sees but a small advance on recent barbarism in ways of life simple in some respects but rich in developed art and stored with refined tradition; that looks only for the ways and habits and thoughts of primitive man in races supported by a background of philosophical and scientific culture of an unfathomed, and maybe unfathomable, antiquity. Behind early Hellenic civilisation was all the wisdom of Egypt and the East, and the first Greeks of whom we have knowledge looked upon the old Heaven and the old Earth not with the half-open, wondering eyes of wakening intelligence, but with perceptions trained in an ancient inheritance of accumulated learning.

On gold coins of Crœsus we find our two symbols of the Lion and the Bull, sometimes facing one another, sometimes joined by their necks. Whatever may be precisely signified in the latter case, it seems to me plain enough that the collocation of the two animals here, together with the presence of the Lion alone, or of the Lion with other animals, on coins of the same place and period, should make us hesitate to see in this Ox-type the emblem and memento of a primitive trade: apart even from the inherent improbability involved in supposing that the Ox was the great staple of commerce and fixed standard of value over mainland and islands, through regions inland and maritime, among people peaceful or warlike, stationary or nomadic, pastoral or mercantile; while any argument that, in this particular case, we had the old trade-symbol of the Ox coupled with the Lion as a personal or dynastic crest is negatived by the frequency and wide distribution of the same two figures in conjunction.

FIG. 3.—Coin of Crœsus.

If the Lion and the Bull in combat represent zodiacal signs, we should expect them to do so in like manner when figured separately or when associated with other symbols. Numismatists have long recognised the Lion on coins of Leontini, Syracuse, Apollonia on the Euxine, &c., as a solar symbol*: it is evidently in relation to the sign Leo that it is so; and I need scarcely remind the reader that the same sign is, in fable, the Lion of Nemea, with whose defeat the solar Hercules began the cycle of his labours.†

* *Cf.* HEAD, *Hist. Numorum*, pp. 131, 152, 236, &c.

† *Cf.* DUPUIS, *Origine de tous les cultes*, i. p. 191, &c. From this learned and original work, oftener quoted, as CREUZER says (*Symb.*, iv. p. 696), than acknowledged, I have got great help, not in the inception but in the elaboration of my theory.

Let us defer for the present the consideration of planetary signs in conjunction with zodiacal ones, but let us pause to consider a few more representations of the zodiacal emblems when displayed alone. In perusing a series of figures of coins or gems, we often meet with the same animal in duplicate, forming a pair of symmetrical and identical but opposed figures; and the pair of figures, or in some cases three placed triradially, are sometimes set in a figure of revolution. It seems to me that I find such figures mainly in connection with the tropical or solstitial signs, and sometimes also with the equinoctial ones. Taking the former case, we have to deal with the ancient tropics of Leo and Aquarius and the later ones of Cancer and Capricorn; while our corresponding equinoctial signs are, more anciently, Taurus and Scorpio, and in the later epoch Aries and Libra or, as an equivalent to the latter, the Chelæ of the Scorpion. Of these, the Crab, the Balance or its substitute the Claws are in themselves marked by a bilateral symmetry so conspicuous that we need not seek for further reduplication. In the case of Aquarius I have not found such a symmetrical reduplication, unless the bilateral form of the two-handled Jar be in itself its equivalent. But in all the other cases I find it.

FIG. 4.—Coin of Amphipolis.

FIG. 5.—Coin of Delphi.

FIG. 6.—Archaic Gem (I. B. and K., pl. xix. 1).

An archaic bracelet, reproduced and familiarised by Castellani, consists of a split ring, whose two ends are fashioned into the semblance of Rams' heads; the whole ornament is, to my thinking, a symbol of the year, from Aries to Aries. We have a similar notion expressed in the annexed figures of the two Goats or in the corresponding one of the two Rams; these I take to be emblematic of the dividing line of the solstice or equinox, as the succeeding figure illustrates the pivot-point of the equinox in Taurus, with the Moon in conjunction. And turning from glyptic or numismatic to monumental art, we think at once of the twin Lions guarding their central column on the Lion-gate at Mycenæ: that column I take to be the Lion-guarded pillar of the solstice; I fancy it was once crowned with a solar globe; and I furthermore venture to prophecy that that temple-gate will be found in some manner oriented to the midsummer sun, as is the great avenue of our own astronomical temple of Stonehenge.

From a study of the Lion and the Bull we are led, somewhat unexpectedly, to a consideration of the Pleiades. This notable constellation occupies a remarkable position: it is set in the sign of the Bull, and very nearly at the intersection of the ancient equator and the ecliptic. In astronomical descriptions the place of the constellation

varies somewhat in relation to the imaginary and variable figure of the Bull. HIPPARCHUS set it near the Bull's thigh, but it is more usually and more anciently placed, as by ARATUS, on the Bull's back. In many languages the Pleiades are mixed up with the names or images of birds. Besides the well-known and ancient belief that πλειάδες was originally πελειάδες, we have the fact that the Chinese still picture the constellation as a bird, and the existence of the old English name "the Hen and Chickens," to which correspond the French *Poussinière*, the *Pillalou codi* of the Indians, the *Succoth Benoth* of the Hebrews, and many similar names. Add to these the names of the individual stars themselves, or so many of them as we can understand. The first Pleiad is Ἀλκυόνη, the Halcyon, and the second is Μερόπη, which is connected not only with μέροψ but with the remarkable word μεροῦπας, which Mr BENT found used in Syra in the Cyclades to mean simply a bird, ὄρνις. I think from all these analogies I am justified in taking the bird figured on the Bull's back in coins of Eretria, Thurium, &c., and on Egyptian representations of the Sacred Bull, to be nothing more nor less than the associated constellation of the Pleiades.

FIG. 7.—Archaic Gem, probably Parthian. (Imhoof-Blumer and Keller, pl. xxi. 14).

FIG. 8.—Tetradrachm of Eretria.

Not to be dissevered from this connection is the story of the Dove of the Argonauts, which flew between the clashing rocks in the passage of the Hellespont. Was not that Βόσπορος a transit through the Heavenly Bull, and is it going too far into the regions of hazard to see in the *Sym-Plegades* a name (corrupt by popular misunderstanding) akin to *Plejades*?

In considering the relative positions, at critical periods, of the Sun and the Pleiades, we seem to light on an explanation of the great myth of the Halcyon's Nest. On the day of the winter solstice, mid-winter's day, the Pleiades occupied at sun-set the mid-point of the heavens :—

νὺξ μακρὴ καὶ χεῖμα μέσην δ' ἐπὶ Πλειάδα δύνει,

"The Pleiad is in mid-heaven as the long(est) winter night sets in." It was precisely at this period that the Halcyon was said to lay her egg, when the turning sun rose to renovate the year. What is the meaning of the line following that which I have just quoted :—

νὺξ μακρὴ καὶ χεῖμα μέσην δ' ἐπὶ Πλειάδα δύνει,
κ' ἀγὼ πὰρ προθύροις νείσσομαι ὑόμενος,

"I stand in the door-way dripping from my bath." That is what the Sun says as he emerges from Oceanus.

A consideration of the account given in ARISTOTLE (*H.A.*, bk. v. 8, 542 b) and of the citations made there from SIMONIDES, compel us to interpret the phenomenon as astronomical:

ἡ δ' ἀλκυὼν τίκτει περὶ τροπὰς τὰς χειμερινάς, διὸ καὶ καλοῦνται ὅταν εὐδιειναὶ γένωνται αἱ τροπαί, ἀλκυονίδες ἡμέραι, ἑπτὰ μὲν πρὸ τροπῶν, ἑπτὰ δὲ μετὰ τροπάς, καθάπερ καὶ Σιμωνίδης ἐποίησεν, Ὡς ὁπόταν χειμέριον κατὰ μῆνα πινύσκῃ Ζεὺς ἤματα τεσσαρακαίδεκα, λαθάνεμόν τέ μιν ὥραν καλέουσιν ἐπιχθόνιοι, ἱερὰν παιδοτρόφον ποικίλας ἀλκυόνος. Γίνονται δ' εὐδιειναί, ὅταν συμβῇ νοτίους γίνεσθαι τὰς τροπάς, τῆς Πλειάδος βορείου γενομένης.

We may render the last lines of this passage as follows:—"And the fine weather is to be met with when the sun turns in his southern tropic, and when at the same time the Pleiades are found in their highest (northern) elevation." *

The Pleiades had also an intimate relation with the season of spring. In the ancient epoch of which we speak, when Taurus was the equinoctial sign, the sun rose associated with the Pleiades at the Vernal Equinox, in what was the opening of the ancient year; for this reason the Pleiades were the stars of spring, the Vergiliæ of the Latins. And the Halcyon is the same as the

ἁλιπύρφορος εἴαρος ὄρνις,

a verse which admits, syllable for syllable, of literal translation, not merely "the sea-blue bird of March," but "the bird of spring that brings up the sun from the sea."

M. SVORONOS has pointed out that the numismatic emblem of a bunch of grapes is to be looked upon as another representation of the constellation of the Pleiad. An Homeric Scholiast† tells us that Βότρυς was actually a name given to that constellation; and M. SVORONOS figures a very remarkable coin of Mallos in Cilicia, where doves are represented whose bodies are formed of bunches of grapes, the dove-emblem and the grape-emblem of the Pleiad being here united or intermixed. The case is a very interesting one, because it seems to give an example not only of the influence of foreign symbolism, but of the direct influence of *loan-words* from foreign sources. I take the grape-symbol to be due to a substitution of the notion of οἶνος for οἰνάς, a rare pigeon-name; and the latter to be nothing more than the Semitic יונה, Ionah, a dove.

Having started our discussion with the Lord of Beasts, let us glance at the symbolic attributes of the King of Birds; but of these symbolic attributes, which are innumerable, we may be content with a very brief discussion. The Eagle is depicted in Greek Art and Literature as hostile to various creatures, of which the chief and the most frequently mentioned are the Swan and the Hare. I find nothing of zoological significance in these relations. The eagle does not prey upon swans; and though it may catch here and there a leveret, the hare is certainly not one of its main objects of attack.

* For further remarks on this obscure and difficult myth, see my *Glossary of Greek Birds*, pp. 31, 32.

† *Schol. Il.*, xviii. 486; IDELER, *Sternnamen*, p. 317.

Reading the statements in the light of astronomical symbolism, we are at once struck by the following circumstances. The constellation Aquila is adjacent to the constellation Cygnus; the former rises immediately after and as it were in pursuit of the latter, but the Swan, lying further to the north, has a longer course to make above the horizon, and accordingly is still visible for a while after Aquila has set. ARISTOTLE tells us, in a passage of hitherto unquestioned zoological import, that the Eagle attacks the Swan, but is in turn defeated by it. I can find no zoological truth in the statement, but the astronomical coincidences here related accurately correspond to it. As regards the Hare, we note that the constellation Lepus is on the eastern horizon when Aquila is precisely on the western. Not far from Aquila stands the constellation Vultur; and Aquila and Vultur are frequently associated together, both by classical writers and by the Arabs, as Aquila or Vultur cadens and volans, or *γὺψ καθήμενος* and *πετόμενος*, nesr-el-wâki and nesr-el-tâïr, whence our modern names Vega and Altair applied to their two principal stars. These, then, are the two eagles that devour the Hare on the famous decadrachm of Agrigentum and in the great simile of the Agamemnon, *οἰωνῶν βασιλεὺς βασιλεῦσι νεῶν. ὁ κελαινός, ὅ τ' ἔξοπιν ἀργᾶς, . . . βοσκόμενοι λαγίναν.*

FIG. 9.—Decadrachm of Agrigentum.

It remains to be seen whether we can discover any reason for these particular phenomena of the heavens attracting particular attention and being especially selected for representation. The Hare rises, and the Eagle, pursued by the Swan, sets just as Cancer has risen. The Crab is in like manner a frequent subject on coins, and in some very beautiful coins of the same city of Agrigentum we have the Crab on one side and the Eagle on the other. The whole symbolism probably, therefore, has reference to the tropic of Cancer, and to the midsummer rising of the sun in that sign in the classical epoch as in the older days it was at the same season of the year associated with Leo.

The multitudinous numismatic representations of the Dolphin (on coins inland as well as maritime) provide us with a severe test of the validity of the astronomic hypothesis. The constellation of the Dolphin set very nearly as the Lion, the Hydra, the Hare, and the Dog-star rose; it is associated with the Lion on coins of Syracuse, Tarentum, Velia, and Nacona, with the Serpent on coins of Priansus, Motya and Messene, with the Hare on those of Messene, and with the Dog on those of Phocaea.* With the circumstance that it stood directly opposite to the Lion, setting as the latter rose, we may correlate its title of King of Fishes under which it ruled side by side with the King of Beasts, reigning over Oceanus while the Lion was Lord of the visible sky. It stood, with Capricorn, in mid-heaven at the rising of Aries, and is associated with the Goat and Ram on coins of Delphi and with the former animal on those of Paros. It rose as Argo and Gemini set, and is figured with a ship on coins of Megara

* As well as on a gem figured by IMHOOF-BLUMER and KELLER, pl. xx. fig. 18.

and with the Dioscuri on coins of Tarentum. It rose with Sagittarius, and together with it on coins of Tarentum we have Taras (?) armed with a bow and arrow. In its place in the heavens it is closely encircled by Pegasus, Cygnus and Aquila; the Eagle is found with it on coins of Messene, Istrus, Motya and Sinope, and the Swan on those of Argolis; while Pegasus is associated with it on coins of Corinth, and is probably also to be understood in the Horse of Rhaucus and the Horse and Rider of Tarentum.

The statement in ARISTOTLE (*H. A.* vi. 12, 566b) that the Dolphin disappears for a month in summer, *συμβαίνει δὲ καὶ ἀφανίζεσθαι αὐτὸν ὑπὸ κύνα περὶ τριάκονθ' ἡμέρας* (regarding which statement AUBERT and WIMMER naively say, "über diese Verhältnisse scheinen aus neuer Zeit gar keine Beobachtungen zu existiren") is simply an astronomical fact concerning the constellation, interpolated into a passage in the main zoological. It was probably the same constellation under another guise that Apollo had to overcome ere he mounted to the sky: *Δελφίνην δ' ἐδάμασσεν, καὶ αἰθέρα ναῖεν Ἀπόλλων*, NONN. *Dionys.*, xiii. 28. And, passing over a hundred fables all bearing kindred astronomic reference, let me cite one more circumstance in point. We are told by PAUSANIAS (vi. 20, 7) that a brazen Eagle and Dolphin guarded the *ἄφεσις* at Olympia *; and when we bear in mind that in the heavens Aquila and Delphinus stand opposite to Leo, does it not seem fit and proper that the Eagle and Dolphin should mark the end of the Olympian chariot-course, where the fabled Slayer of the Lion laid down the mimic race-course of the Sun?

The Owl on Athenian coinage is an emblem of great interest, but involved in not a little difficulty. SVORONOS takes it, with some hesitation, to correspond to the constellation simply known as *Ὄρνις*; but that "bird"-constellation is, in all cases that I am acquainted with, identical with Cygnus the Swan. Although the Owl on Athenian coins is sometimes associated with a lunar crescent, I am, for my part, inclined to look upon it as itself a lunar emblem. We may call to mind, in support of this view, the Euripidean fragment,

γλαυκῶπις στρέφεται μήνη,

And remembering that Athene in HOMER is always nocturnal, and is even definitely stated by PORPHYRY (*Euseb., Pr. Ev.* iii. 11) to have been a Moon-Goddess, we find not a little to support the hypothesis. In the light of this conjecture, the common association of the Owl with an Amphora on Athenian coins becomes interesting; for it may be that the Amphora is the symbol of Aquarius, and the relation of Aquarius to the Moon has been discussed already.† When Athene in the *Iliad* appears in the shape of a

* As also in the Circus Maximus at Rome; *cf.* JUV. vi. 590, DION. CASS. xlix. 43.

† The study of what I take to be the lunar symbolism of the exclusively silver coinage of Attica, and other considerations of a like nature, have led me to the discovery of a singular and suggestive coincidence. We are told by HERODOTUS (iii. 89) that the values of gold and silver in ancient currency stood to one another in the ratio of 13 : 1; but MOMMSEN (*Hist. Mon. Rom.*, ed. BLACAS, i. p. 407; *cf.* HEAD, *Hist. Numorum*, p. xxxv.) and others have shown that this statement is only approximately correct, and that the true ratio was 13·3 : 1. There is no evidence that there were the same fluctuations between the relative values of the two metals which are now so common (HEAD, *l.c.*). Two problems are here presented to us for solution: first, How was this ratio kept steady and unchanged during many

swallow, there again the lunar crescent of the swallow's wings is at once suggested to me; and the similitude to the swallow of Ulysses' bow is of the same nature: no twittering swallow's note was ever like to the twang of the great bow, but the bow was bent like the crescent wings of the bird, *χελιδόνι εἰκέλη ἄντην*.

To draw yet another illustration from the mystical Kingdom of Birds, what was the pitiful lay of *ἀδωνηίς*, *ἀδονίς*, *ἀηδονίς*, or *ἀηδών*, that fills line upon line of Attic chorus and Dorian and Ionian hymn with obtrusive melancholy? Was it not simply the old dirge of *Adonis*, the Dead March of the year, the keening song over the grave of the Sun, whom the sorrowing East bewailed when women wept for *Tammuz*? Was it not merely a disciple of another sect who said he preferred the swan's song to the nightingale's?

Whether this or some other be the true explanation of the legend of the nightingale's song, it is quite plain from the frequent hints of many writers that some esoteric meaning was associated with the songs of Halcyon, Nightingale and Swan. LUCIAN, for instance, gives us such a hint and a very notable one, though even he only points, with sealed lips, to the immemorial riddle whose solution he cannot or must not tell: *οὐκ ἂν ἔχοιμεν εἰπεῖν βεβαίως οὔτ' Ἀλκυόνων πέρι, οὔτ' Ἀηδόνων· κλέος δὲ μύθων, οἷον παρέδοσαν πατέρες, τοιοῦτο καὶ παισὶν ἐμοῖς, ὦ ὄρνι θρήνων μελῳδέ, παραδώσω τῶν σῶν ὕμνων πέρι, καί σου τὸν εὐσεβῆ καὶ φίλανδρον ἔρωτα πολλάκις ὑμνήσω.*—LUCIAN, *Halc.*

In a certain small number of coins and gems the representation of astronomic phenomena is set forth in clear and concrete fashion, with no riddle of esoteric symbolism. The annexed figure of a gem (from Asia Minor) represents in this obvious way the constellations of the Dragon and the two Bears:

> Maximus hic flexu sinuoso elabitur Anguis
> Circum perque duas in morem fluminis Arctos.—VIRG., *G.*, i. 244.

centuries of antiquity; and, second, how or why was it chosen and established in the first instance? Now, it seems to me more than a mere coincidence that 13·3 : 1 :: 365 : 27·4, the last number being precisely the period in days of the Moon's revolution round the earth. In short, the ratio of gold to silver, established and maintained, I fancy, by astronomic science and astrological superstition, was simply and precisely the ratio of the solar year to the lunar month, the natural relation of the metal of the Sun to the metal of the Moon.

If this speculation be justified, it may further throw some light on the use of electrum as a standard of currency. This metal was an alloy of gold and silver in the proportion of 73 to 27; and it has been pointed out by HULTSCH that its value according to this scale would be to silver as 10 to 1, when gold was to silver as 13·3 to 1:—that is to say, gold : electrum : silver :: 13·3 : 10 : 1. It is generally assumed by numismatists that electrum was a native alloy, coined for convenience to avoid the trouble of separating the silver from the gold. This explanation is in my opinion altogether inadequate. The very fact that the ancients knew accurately the composition of the alloy is enough to indicate that the separation of the two metals presented no serious difficulties to them: moreover, I do not believe that an alloy of so precise a composition ever existed in large quantity or widely distributed: and, lastly, though some such alloy undoubtedly did exist native, we are twice told by PLINY (*H. N.* ix. 65, xxxiii. 23) that it was made or imitated artificially. It seems probable to me that electrum was an alloy ingeniously devised and skilfully manufactured to form a new standard in simple decimal relation with silver, to take the place of the old, complex and inconvenient astronomical standard of gold. And the ingenious framing of a $\frac{10}{1}$ in place of a $\frac{13{\cdot}3}{1}$ ratio and standard would form a parallel case to the splendid adaptation by which the Babylonians divided the circle into 360 degrees, thus, by a slight and simple change, co-ordinating with a sexagesimal notation, the old 365 or 365¼ degrees into which the Chinese still divide the circle, as the Sun divides the circle of the year.

Imhoof-Blumer and Keller, from whose *Thierbilder* I have borrowed the figure, simply state that these three constellations are represented; but they do not state, and perhaps did not perceive, that there is a deeper astronomic interest in this gem, to wit, that as nearly as may be its centre coincides with the North Pole of the heavens in the epoch of classical Greece. The pole, which now lies in the Little Bear, then stood in Draco between the Two Bears, somewhat nearer to the little one; and the Two Bears are the Miltonian "Star of Arcady and Tyrian Cynosure,"

Fig 10.—Draco and the Two Bears on an Asiatic Gem.

Magna minorque ferae, quarum regis altera Graias,
Altera Sidonias, utraque sicca, rates.—Ovid, *Tr.*, iv. 3, 1.

The whole gem is an exquisite picture of the polar region of the sky, precisely as Aratus describes it in a famous passage copied over and over again by Latin poets:—

καί μιν πειραίνουσι δύω πόλοι ἀμφοτέρωθεν·
ἀλλ' ὃ μέν οὐκ ἐπίοπτος, ὃ δ' ἀντίος ἐκ βορέαο
ὑψόθεν ὠκεανοῖο· δύω δέ μιν ἀμφὶς ἔχουσαι
Ἄρκτοι ἅμα τροχόωσι (τὸ δὴ καλέονται Ἅμαξαι).
αἳ δ' ἤτοι κεφαλὰς μὲν ἐπ' ἰξύας αἰὲν ἔχουσιν
ἀλλήλων, αἰεὶ δὲ κατωμάδιαι φορέονται,
ἔμπαλιν εἰς ὤμους τετραμμέναι . . . .
καὶ τὴν μὲν Κυνόσουραν ἐπίκλησιν καλέουσιν,
τὴν δ' ἑτέρην Ἑλίκην. Ἑλίκῃ γε μὲν ἄνδρες Ἀχαιοί
εἰν ἁλὶ τεκμαίρονται ἵνα χρὴ νῆας ἀγινεῖν·
τῇ δ' ἄρα Φοίνικες πίσυνοι περόωσι θάλασσαν.
ἀλλ' ἡ μὲν καθαρὴ καὶ ἐπιφράσσασθαι ἑτοίμη
πολλὴ φαινομένη Ἑλίκη πρώτης ἀπὸ νυκτός·
ἡ δ' ἑτέρη ὀλίγη μέν, ἀτὰρ ναύτῃσιν ἀφείων·
μειοτέρῃ γὰρ πᾶσα περιστρέφεται στροφάλιγγι·
τῇ καὶ Σιδόνιοι ἰθύντατα ναυτίλλονται.
τὰς δὲ δι' ἀμφοτέρας οἵη ποταμοῖο ἀποῤῥώξ
εἰλεῖται μέγα θαῦμα, Δράκων, περί τ' ἀμφί τ' ἐαγώς
μυρίος· αἱ δ' ἄρα οἱ σπείρης ἑκάτερθε φέρονται
Ἄρκτοι, κυανέου πεφυλαγμέναι ὠκεανοῖο.—Arat., *Ph.*, 25–48.*

And now, to close my story, the conclusion that I wish, in a general way, to draw is, that to understand the solemn and sacred and cherished myths of antiquity, we must seek an interpretation in their ancient source in an ancient heaven. The one science that the civilised races of old loved and understood was astronomy.

* *Cf.* Virg., *G.*, i. 244 (*supra cit.*); Ovid, *Met.*, iii. 44; Id., *F.*, iii. 107; Lucan, iii. 219, viii. 173, ix. 539; Sil. Ital., *Pun.*, iii. 192, 665, xiv. 456; Val. Fl., i. 17, v. 69, vi. 40, &c.

"Their Wise Men
Were strong in that old magic that can trace
The wandering of the stars."

The Herald in the Agamemnon was not a solitary watcher of the skies, nor did Wise Men in the East monopolise the adoration of the stars; but generations of Hellenic priests, like their fathers and their brethren in Egypt and Chaldea, had regarded the strength of Mazzaroth and the bands of Orion and the sweet influences of Pleiades.

These guardians of an esoteric knowledge divulged their store little by little, in myth and allegory, in the sacred art of sculptor and of poet, and through the mystified lips of the teller of tales and the singer of songs. The traditional belief that Perseus and Boötes, Cepheus and Heracles, were earthly heroes translated to a restful seat in the stellar firmament, is an inversion of the true order of things. The Heroes that were set in the sky had been drawn thence in the beginning: the Gorgon's head was not the creation of a poet's fancy nor the legend of an antique chronicler, before a place was found for it in the star Algol; but patient study and accurate knowledge of the Demon Star, with its mysterious flashes and its rhythmical wax and wane, preceded the allegorical conception of Medusa's snaky head.

Let us, then, forsaking traditional acceptations, admit that the Chimæra must be carried at once to the land of Chimæras; that Perseus and his Gorgon's head must not be taken to Lycia, nor Amalthæa and the two Bears to Crete, but that all of them must be raised to the sky. In all these cases earthly geography must be left aside. The Bull, the Crab, the Goat, and the Ram on silver drachma and golden daric must not be regarded as articles of trade, but must be placed in the zodiacal ring. The voyage in quest of the Golden Fleece was not through the Dardanelles, towards Colchis or the Caucasus. No dove out of a dove-cot was set free between the clashing Symplegades. Further, if to these zoological illustrations we add the number of the Achæan chiefs at Troy or of the champions on either side at the epic siege of Thebes: if we couple Helen, Queen-Goddess of beauty (the moon-faced beauty of the East), with her twin stellar brethren: if we think of the Phæacian King, whose sailors sailed from his far western island to eastern Eubœa, saw there, on the triple judgment-seat, Rhadamanthus or Ra Amenti and his brother-kings of the under-world, and returned in one day home again, we catch more than a glimpse of that stellar symbolism which veiled from vulgar eyes, even perhaps from the eyes of the tellers of the story, a splendid vista of priestly lore.

The stellar symbolism that I here advocate is, I maintain, a different thing from the sun-myths, dawn-myths, and so forth, which are now to a large extent deservedly repudiated. We cannot ascribe to the civilised nations of antiquity the puerile conceptions of nature that are congruent with a stage of awakening intelligence and with the crude results of untrained observation. Rather are we dealing with the elaborated gain of ages of scientific knowledge, with the thoughts of a people whose very temples were oriented to particular stars or to critical points in the journey of the sun; whose representations

of Art, on frieze and pediment, in tragedy and epic, were governed by what would at first appear to be a tyrannical convention : which convention, however, so far from hampering their genius, seems, under the influence of a wholesome restraint, to have moulded their art into more beautiful, more poetic, and more sanctified forms.

And we may stay a moment to remember that it is not only Art but Custom also that was fettered by conventionality and sanctified by religion. At Olympia, in the beginning of each Leap-year cycle, the noblest youth of Greece raced, round the symbolic pillars, their horses emblematic of the Horses of the Sun ; thereby glorifying a God whom they thus ignorantly worshipped. Even so, we read in the second Book of Kings how their Phœnician cousins worshipped with like ceremony the same God. And all the while, in the evening and the morning, priests and *πρόσπολοι* watched, measured, and compared the rising and setting of Sun and Stars, in temples that were astronomical observatories, to the glory of a religion whose mystery was astronomic science.

This dominant priesthood, whose domain was knowledge, holding the keys of treasured learning opened the lock with chary hand, and veiled plain speech in fantastic allegory. In such allegory Egyptian priests spoke to Greek travellers who came to them as Dervish-pilgrims or Wandelnde Studenten. It was this Sybilline knowledge that an Æschylus, an Ovid, or a Virgil, Master of Wizards, here and there half revealed. It is this dragon-guarded treasure of secret wisdom that we may yet seek to interpret, from graven emblem, from symbolic monument, from the orientation of temple-walls ; from the difficult interpretation of non-Hellenic names, of hero and heroine, of Solar God and Lunar Goddess, of mysterious monster and fabled bird, of celestial river and starry hill : names that were first written in the ancient and learned language of a people wiser and more ancient than the Greeks.

IV.—*Two Glens and the Agency of Glaciation.* By His Grace The Duke of Argyll, K.G., K.T. (With a Map.)

(Read 1st April 1895.)

The group of questions which are connected with the Glacial Age seem to me to be among the most interesting and the most difficult in the whole science of geology. They include the question of Time—since, perhaps, the only hope we have of even reaching any unit of time in geological changes lies in the phenomena of the Glacial Age. The question of the comparative slowness or suddenness of great physical changes is not less directly involved. Bound up with this again is the question of the sudden or slow destruction of the extinct forms of life, and the introduction of new forms to replace them. The connection between Cosmical and Terrestrial causes of change comes directly into our view, and then the nature and operation of the terrestrial forces which were brought into play. I am very sceptical as to many of the solutions which have been proposed for most of these questions, and still more for the theories which profess to answer them as a whole. There is nothing to be done but to accumulate evidence in detail—to observe facts well, that is, completely—and avoid looking only at such of them as tell in favour of some preconceived hypothesis.

It is one of the great delights of the physical sciences that the questions they concern are inexhaustible. I do not mean only that each one of those questions always leads on to some other. I mean that even each question in itself is always turning up in some new light, or new aspect, even when we may have been long familiar with the phenomena which suggests it. The truth is that the very fact of such familiarity is perpetually the cause of some fresh departure, because it extinguishes that sense of surprise, and puts even that natural curiosity to sleep, out of which all intelligent questioning of Nature comes. Things which we see every day are precisely those which are most apt to conceal their lessons from us—and it is only, perhaps, some accidental suggestion that awakes us to obvious interpretations which we had never thought of before. Such, I confess, is the experience I have lately had concerning a question in geology which I have long regarded as of the highest scientific interest. I refer to the physical agency, and the physical conditions under which what is known as the glaciation of our West Highlands was effected. The science of geology presents no more perplexing problem. Living, as I do, in a country where the marks of glaciation are abundant, but at the same time far from universal over the whole surface, I have long come to the conclusion that one agency widely believed in cannot possibly have been the producing cause. It cannot have been what is called an Ice Sheet, or an Ice Cap, or ice in any form, under whatever name it is

called, which moved upon, and moved over all the hills, in enormous masses, and therefore with an enormous pressure universally applied. The marks appear to me to be incompatible with any such supposition. They are essentially partial, local, and what may be called selective. We cannot attribute this partiality to the disturbing effects of subsequent obliteration; because the same rock in the same place which is highly glaciated on some one part of its surface is wholly untouched upon other parts. Some rock surfaces, indeed, do exist, which have been evidently wholly covered by, and ground down under enormous and continuous moving pressure into one smoothed and polished floor or dome, and these rocks are of the greatest interest in showing to us what the characteristic effects of such an agency must always be. But though they exist, they are comparatively rare. For every one specimen of this kind of glaciation there are hundreds of thousands in which the smoothing, abrading, or scratching agency has acted on some one side of a rocky surface and has left the other side rough and untouched. There is, however, one general rule or law which can be clearly traced. The direction from which the agency came, and the direction towards which it moved, is almost always determined by the existing configuration of the land,—that is to say, rocks on the sea-shore have been smoothed by some body which must have moved along the coast from the higher hills towards the lower ranges, or towards the outlets of the arms of the sea on which they are abundant. In like manner, in the glens not occupied by water, they follow the lines of the glen from its head towards its opening. So far, this is easily intelligible, because, if the configuration of the country was substantially what it is now, ice moving in the form of ordinary glaciers, such as those of Switzerland, would, and must, be guided in their course by the direction of the hollows in which they lie, or, if moving in the form of floating or floe-ice, would equally be guided by currents similarly determined. But there is this difference to be noted, that even small glaciers, such as those which we now have on the Alps, do produce surfaces wholly polished upon those particular rocks over which they actually move in a solid mass. Very partial glaciation, therefore, such as leaves large parts of a rock wholly untouched, cannot indicate the passage of ice in this particular form, whilst it is not only consistent with, but characteristic of ice floating in water, and made by currents to impinge upon rocks which interrupt its passage. The floating masses grate along the shores, or the rocks which constitute a shore for the time being—catching the projecting surfaces as they pass, and necessarily leaving untouched the retired or sheltered surfaces, which do not obstruct the way. Then there is one phenomenon, which clearly indicates the same agency—although under the same conditions, which startle us not a little—and that is the glaciation of rock surfaces which constitute the summits of high hills, far above the general level of the whole country, and not situated in any glen or hollow which could possibly have guided either a solid glacier or a mere shore current. These glaciated tops are often smoothed or striated on one surface only—with a sheltered side as rough and as well-marked as any similar rock upon the existing shores. This is quite inconsistent with the passage of that enormous kind of glacier which is denoted under the name of an Ice Sheet or an Ice

Cap. Such a body could not have failed, by its vast pressure, to have ground down all the surfaces on which it rested, or over which it passed; and the appearances actually presented are generally quite distinctive of an agency much lighter and more passing in its work. The same lesson is taught by another phenomenon very common on our hills; and that is the position of enormous boulders and masses of rock left poised or "perched" upon the very tops of ridges, isolated hills, in such a manner that no conceivable agency but that of floating ice-floes could have placed them and left them where we now see them. Nor are these blocks deposited only on the tops of conspicuous hills, but also on knolls and elevations of every sort and kind, just as would naturally happen on shoals and banks in a rising or falling sea. Moreover, it is to be observed that many of these stones are not rounded, as they must have been if they had been rolled under water, or dragged along in the lower layers of a moving glacier. Many of them are rough, and even angular in a high degree—just as they might have fallen from some overhanging cliff, or have been torn off by the splitting power of frost. These are all arguments to show that even if an ice sheet had ever existed as a moving mass, it could not have produced the phenomena which we actually see. But besides these arguments, there are others which condemn the supposed ice sheet as a physical impossibility—inasmuch as no adequate cause of motion has ever been made out for such an assumed "flow" of such ice-masses.

Putting all these considerations together, I had long come to the conclusion that our glaciation has been effected mainly by ice-floes and occasional icebergs in a glacial sea, which rose at least some 2000 feet above the level of our present ocean, and in which powerful currents were running in a general direction from N.E. to S.W. There is a natural and legitimate aversion to such an explanation. It defies altogether that impression of the stability of the relative position and levels of sea and land, which is one of the strongest preconceptions we derive from our own uniform experience. Forgetting how very short that experience is, and how inadequate to justify any conclusions as to an unknown past, our preconception is farther helped by the extreme difficulty of even imagining any physical cause for a submergence of the land, which would seem to have been so recent and so passing. These are excellent reasons for reserve and caution in our reasoning, but they are no excuses for reluctance in admitting the evidence of obvious facts, or for carelessness in making closer and closer observation as to facts which may not be equally apparent at first sight. After all, we must remember that geology has made us familiar with the idea of the interchangeability of sea and land, almost everywhere over the globe, as one of its most certain facts; and the assumptions, so often tacitly made, that all those changes must have been always infinitesimally slow, are assumptions in the highest degree precarious, and founded on theories for which there is really no adequate foundation. We must remember also that the movements which are suggested, although they startle us by their evident recency in point of time, and by our conception of their magnitude in elevation and depression, are, after all, movements of infinitesimal smallness when considered with reference to the size of the globe, and with

reference to such forces as we know to have worked, and to be still working in its interior. A movement of elevation or of depression in any part of our terrestrial surface, to the extent of 2000 feet, would be quite invisible to a spectator standing at the distance of a few hundred miles, and might easily be produced by the operation of such causes as we see must have been concerned in a thousand cases of geological change. In this, as in all other cases of reasoning on physical phenomena of this class, what we have to look for, above all things, is not merely simple effects, which may plausibly be accounted for by invoking some one supposed cause; but for those complicated and complementary effects which, in great variety and number, are sure to accompany the operation of such great physical forces as those which we may invoke. The evidence which we should seek is essentially cumulative—full of incidental and subsidiary testimony arising out of a thousand facts, which, at first sight, may not seem to have any bearing upon each other, or upon any common explanation. And this is precisely the kind of evidence which only comes to us gradually—as the result of long and continuous observation illuminated by equally continuous thought. Suggestions, indeed, may arise in our minds quite suddenly, and may be of such a character as to be of the highest value, throwing a flood of light on conclusions which had before seemed to rest on a basis hardly adequate to support them, but which now seem very largely confirmed if not actually established.

A suggestion of this kind has lately occurred to me in respect to the agent of glaciation in the Inveraray district, from certain facts with which I had, indeed, been long familiar, but which I had never before put together in connection with this particular problem. This suggestion it is my object in the present paper to explain.

The parish of Inveraray occupies some ten or eleven miles of the north-western shore of Loch Fyne, and reaches to within three or four miles of the extreme end or head of that long and very deep arm of the sea. The large fresh-water lake of Loch Awe lies in another deep depression, which, roughly speaking, lies parallel to this upper reach of Loch Fyne; and the two sheets of water are separated from each other by a range of hills from six to seven miles across from shore to shore "as the crow flies." The trend of Loch Fyne is in that general direction of N.E. and S.W. which is so conspicuous a feature in the physical geography of the West Highlands. The parish is deeply trenched by two great leading glens which join the main valley of Loch Fyne at an acute angle—running pretty nearly north and south, but with some deviation towards the prevalent N.E. and S.W. These two glens, named respectively Glenaray and Glenshira, are nearly parallel, separated by a range of hills and moors hardly exceeding two miles in breadth. This range terminates abruptly in the curious conical hill of Duniquoich, which rises immediately above the town and castle of Inveraray. As the whole country is occupied by one great geological formation, these two glens, which traverse it in such close proximity to each other, might well be expected to present a close resemblance. It is true, indeed, that the rocks of the district have a certain variety, which is quite competent to produce in close proximity considerable varieties of aspect. They consist of the whole series comprehended in the general name of the Mica Schists, together with great masses of

ntrusive material, these for the most part being a porphyritic granite. As the Mica Schists include not merely beds of mica slate but beds also of quartzite and of limestone and of a material which has been suspected to be stratified volcanic ash, there is ample room for the agencies of denudation to do a good deal of differential work—quite capable of accounting for many different aspects of the surface. Moreover, as the sedimentary beds are all more or less inclined at a high angle, glens cutting through them are liable to have sides or walls, some of which present the slope, and others the escarpment sides of the strata, according to the direction in which these are traversed. But if due attention be paid to those causes of a certain amount of difference in the scenery, we can easily separate them from other causes which have operated in other ways. In the case of these two glens there are some special differences which are very striking. The separating wall of mountain is common, of course, to both glens, and the two other, containing ridges to the west and east respectively, rise to about the same elevation, and consist very much of a repetition of the same, or closely similar beds. Yet, in spite of their close structural resemblance, the two glens present a violent and curious contrast to each other. The mountain slopes on either side are as steep in the one glen as in the other. But in Glenshira they are comparatively smooth and regular in surface, showing the slopes and escarpments on either side clearly, and unencumbered by rough knolls or lower ranges of hill. The bed or bottom of the glen is still more remarkable in the same way. It is a smooth and level valley, occupied by a rich alluvial soil, and running about four miles from the sea before its river reaches the elevation of 100 feet. Its placid, peaceful, and rich pastoral character is very beautiful—but singularly unlike most other highland glens, and reminding us more of the glens and valleys in Westmoreland. Glenaray, on the contrary, on the other side of the same dividing ridge, is in every respect different—it is a typical highland glen, occupied by a rapid brawling river, which plunges over three successive waterfalls and runs the rest of its course down a bed encumbered with stones and rocks. The whole surface of the glen partakes of the same rough and irregular aspect. Along the lower slopes near the river, it is encumbered with enormous quantities of loose stones of every size and shape—some of them of gigantic proportions, and most of them quite unworn and unrounded,—presenting, on the contrary, many sharp angular surfaces. Farther up the glen its floor is largely occupied by great conical mounds of clay, sand and gravel, with a multitude of included stones. They represent typically the boulder clay. Through many of these the line of the public road to Dalmally, on Loch Awe, has been cut—showing sections which prove that these mounds have generally not even a nucleus of solid rock, but are composed entirely of transported materials from the grinding down of the rocks around. The included stones are strongly smoothed and striated—very fine specimens of polishing and striation being common in the sections. In short, the whole course of Glenaray is a conspicuous example of the most characteristic glacial action—of a very marked and violent kind. One side of it—the eastern side—presents a surface of moor full of knolls and mounds all covered with loose transported stones, and rocks of every size and shape. The escarpment to the

west, which is extremely steep—much of it almost precipitous—is, however, free, or almost free, from similar appearances—as if the agency, whatever it may have been, had been deflected to the eastern side, and had scoured out the faces opposite.

Here, then, we have a whole series of contrasted conditions in two closely contiguous glens, which suggest some curious questions. How can we account for the almost complete exemption of the one glen from glacial work, when that work is so evident and so predominant in the other? What is there in the physical configuration, or in the geographical position of the one as compared with the other, which can be rationally connected with this great difference? The moment we ask this question, if we are fully awake to its significance, there is at least one negative answer which is certain. No cause operating over the whole area of the country can possibly be the agency which has thus discriminated so immensely between these two glens. This conclusion seems absolutely to exclude the agency of some universal "ice-sheet" higher than all the mountains, and "flowing" from some gigantic confluent glacier-mass which moved from the German Ocean over the whole Western Highlands. Yet this has been the dream of many writers of the extreme glacial school. Any such agency must, in this particular case, be put out of count—quite apart from the many physical objections which lie against it as applicable anywhere or at any time.

But there is another agency much less theoretical, and much more probable, as applicable to similar phenomena elsewhere—and that is the action of comparatively small local glaciers formed upon the containing hills of all our deeper glens, and taking the usual and natural course of such bodies down the slopes, and passing down the valleys into which they fall. If there has ever been any glacial age at all in Scotland, and if the mountains which we now see were ever at any time during that age above the surface of the sea, and exposed to the usual atmospheric conditions of an arctic climate, the snow must have gathered and consolidated on all the higher elevations into true glacier ice, and small local glaciers must have been formed upon them—just as they are now formed on the higher hills in Norway and elsewhere in Northern Europe and America. That such glaciers must have existed in the Highlands, during the glacial age, is practically certain, and there are abundant evidences of their action in many of our glens. But the curious thing in respect to the cases of Glenaray and Glenshira is that it is impossible to account for the difference between them by supposing that a local glacier had existed in Glenaray and none in Glenshira. This impossibility lies in the fact that, of the two glens, the mountain ranges which fall into the unglaciated Glenshira are far higher, and far more certain to have gathered glacial snows, than those which fall into the highly-glaciated Glenaray. It is true that the more immediate containing walls of both glens are very nearly of the same altitude. But in the case of Glenaray, these nearer ridges and summits lead to no contiguous mountains beyond which are still more elevated, but, on the contrary, fall off at once on every side—towards Loch Fyne, in one direction, and to Loch Awe upon the other. On the other hand, the containing walls of Glenshira, at its head, do lead up to contiguous mountain surfaces of much higher elevation, and

especially to the peaks, corries, and precipices of Ben Buie, which rises to the height of 3100 feet. If local glaciers had been formed anywhere in the whole district, they must have been formed on the tops and flanks of this mountain—and they must have moved down Glenshira if they had acted as all such bodies do elsewhere. Two very deep and long ravines, each of them draining large surfaces of mountainous slopes and moors, fall into the head of Glenshira: and it is quite impossible that, if local glaciers were ever formed in Glenaray, they should not have been also formed, and in much greater volume, at the top of Glenshira. There is, indeed, no comparison between the extent and elevation of the gathering ground at the head of Glenshira and the comparatively trifling area capable of serving the same purpose in the case of Glenaray. The conclusion is inevitable that the agency which seems to have been present in great force in Glenaray, and to have been either wholly absent or else very subordinate in Glenshira, must have been something entirely different from a local glacier—something to which Glenaray was much exposed, and from which Glenshira, on the contrary, was much sheltered.

The question is then forced upon us—whether there is any distinctive feature in the physical geography of the two glens which can afford any explanation to this apparent mystery. But the moment this question is asked, we are guided to a most significant reply. There is one, and only one, great distinction between the two glens—namely, this: that Glenaray terminates in a low pass or watershed only 480 feet above the level of the sea, over which the road passes from Loch Fyne to Loch Awe, and that it gapes as with a bell-mouthed opening to the valley of Loch Awe in the directions of N. to N.E. Glenshira, on the other hand, is a glen completely closed in that direction by successive ridges of mountains, which rise from 1800 and 1600 to at least 2000 feet above the same level, and present no pass at all from the valley of Loch Fyne to the valley of Loch Awe. Looking up Glenaray from the town of Inveraray, we see a low horizon and the peaks of Ben Cruachan, on the other side of Loch Awe, fully exposed to view. Looking up Glenshira from a corresponding point at its mouth, our view is bounded by steep mountainous ridges, which close it completely, and behind these ridges by a high screen of elevated moorland, which constitutes an horizon line of at least 1500 feet high. In short, the one circumstance in which the two glens differ is this—that the one is completely open and unprotected to an agency moving from beyond it in a north-easterly direction, whilst the other glen is completely protected from any such agency by a lofty protecting wall of mountains. Of course, the significance of this great difference is immense the moment we connect it with the idea that the glaciating agency was floe ice floating in a sea which at one time rolled over all our hills up to the level of from 1500 to 2000 feet, and which, in both its rising and in its falling stages, must, of course, have been deflected in its currents by many lower elevations, which would afford complete shelter to some glens from the scour to which others, with a lower watershed, were exposed. It seems to me that all the differences and peculiarities of these two glens, with reference to the marks left by the glacial ages in the one, as compared with the other, are explained by the corresponding distinction between them with reference to the physical geography

of each as now described. And the completeness of the explanation is in no way lessened by the fact that the sides, and walls, and floor, of Glenshira are not absolutely devoid of marks which have been left by the glacial conditions to which the whole country was at one time exposed. Quite near the head of the glen a few mounds of transported blocks do appear on the floor of the glen, and the high slopes on each side are thinly sprinkled with transported boulders—not, indeed, with such large and angular masses as encumber, in immense profusion, the floor and sides of Glenaray; but with rounded boulders scattered here and there over a wide surface,—as if they had been dropped by floes, perhaps gradually melting at great heights overhead, which was then the surface of the glacial sea.

When we stand on the low summit of the road which runs up Glenaray, and try to imagine the scene in front of us when the great hollow of Loch Awe was a deep arm of the sea, it is not difficult to understand how there must have been a tremendous scouring current setting down Glenaray towards Loch Fyne. Immediately opposite to us, on the other side of Loch Awe, is the mountain wall of Ben Cruachan, with its subsidiary ranges stretching to the N.E. and E. Westward and north-westward there is no such barrier—the country is much lower, and a comparatively open sea must have existed in those directions. The distant mountains of Morven and Ardnamurchan rise high over a series of lower elevations, and those mountains might then have been islands, as the Hebridean hills, beyond, are now. To the north-eastward, the mountainous region, which so completely protects Glenshira, is traversed by a deep glen, which opens over a low pass right across to the eastern side of Scotland—leading first to Loch Tay, and beyond that hollow to the continuous valley of the river Tay. Along this deep glen, the engineers have constructed the line of railway from Oban to Callander; and every passenger who has an eye to geology must have observed how the line cuts through immense accumulations of sand and gravel, with boulder stones profusely scattered over all the surfaces of the country. In trying to follow in thought the causes which would operate in any submerged area, we must recollect that such conditions involve the double operation of a time of sinking or submergence, and a later time of rising, or emergence. During both those times, all the natural glens, which cut deeply through the country, must have been the seat of powerful currents guided by the containing walls. Thus, the low pass, which breaks the wall between Loch Awe and Loch Fyne, would at both epochs be a line of scour, and as the emergent movement has been, of course, the latest, its marks would be those with which we should expect to meet especially. Accordingly, all the facts point to this solution of the appearances presented by Glenaray, which are in such remarkable contrast with those of the parallel and adjacent valley of Glenshira.

There are two other valleys, or shallower glens, in the parish of Inveraray, which strongly corroborate the same conclusion as to the glaciating agency which has been at work. These are both glens which run parallel to the bed of Loch Fyne, and are parts of the series of parallel ridges and hollows of which the whole mountain mass consists that separates Loch Fyne from Loch Awe. Along the last and lowest of these hollows,

the road from Inveraray to Lochgilphead has been made, in order to avoid ground which is too precipitous at some places on the shores of Loch Fyne. The summit level of the easier gradients afforded by this glen is only 300 feet above the sea, and along its floor there are stretches of land which lie very low. These are generally occupied by mosses, and they are almost entirely free from boulder-stones. But the top and sides of the somewhat sudden rise, which conducts us to the summit level, are, on the contrary, loaded with transported blocks of stone—some of them more or less rounded, but many others presenting rough and angular outlines. The accumulations of these which have been left on the more prominent knolls and elevations have all the appearance of having been stranded where they now lie by floating ice, which came from the N.E., and, in passing, grounded on the first obstructing rocks and shoals which arrested their progress through the straits. The same explanation, and no other, is suggested by a series of similar blocks which lie on a hill some 500 feet above the same glen. That hill happens to be so situated as to break and obstruct a parallel hollow behind the first ridge to the north, and it raises its steep front exactly in such a position as to front and arrest any agency, whether water or ice, which could have moved south-westward along the hollow. Accordingly, this obstructing hill is covered with great angular blocks of stone, just as it would naturally be if it stood directly in the way of a current from the N.E., which carried along with it floe-ice laden with stones from the N.E. Many years ago I took the late Sir David Milne Home to see this remarkable example of the transported boulders, to which he devoted so much attention, and he was much struck by its significance and its only possible interpretation.

But even more decisive than all other facts, in my opinion, of the nature of the agency which carried the blocks, are the cases of what are called "perched boulders," on the very tops of many of the lower ridges, and even of the highest ridge between Loch Fyne and Loch Awe. Some of those are very remarkable, both as to great size, as to angularity, and as to position. They are so situated that it is impossible to conceive how any other agency than floating ice can have placed them where they are. They cannot have rolled down from higher ridges behind—because their material is generally different, and also because they would have had to roll up steep slopes, and the impetus which would be required for this cannot be supposed to have stopped exactly at the top. Moreover, many of them are not rolled at all, and some are conspicuously angular. On the other hand, such situations are precisely such as would be the natural places, or points, of deposit by ice floating on a sea over an emerging land. Every prominence which is now a ridge must have been a shoal, or ledge of reef, in such a sea at some given time in the process of emergence. Floes, or bergs, stranded on such reefs would necessarily drop their burdens upon these when they melted, and such deposit would always be upon the very top, or close to it.

There is yet another very clear indication of the nature of the glaciating agency in the appearance presented by the hills on the tops of which these perched blocks are situated. In one conspicuous instance, not far from the town of Inveraray, a hill which is crowned

by a large number of perched blocks, is a granitic ridge, 700 feet above the level of the sea, with a steep and partially precipitous face, facing S. and S.E. This face is quite untouched, and rough—showing no trace whatever of any rounding or smoothing agency having passed along it or down it. But the back of the same hill, facing to the N. and N.E., is on the contrary well smoothed and glaciated. Behind and above this hill there is another and a much higher ridge, also granitic, which rises to the elevation of 1000 feet, and presents, like the lower one, a precipitous face, quite untouched by glaciation, towards the S. and S.E. Between the two hills there is a deep hollow, over which, in some parts, many huge blocks of transported stones are scattered. These blocks also are often very angular and unrolled. It is impossible to reconcile any of these facts with the agency of any body of ice large enough to rest upon, and to move along, the whole surfaces of the country. They are essentially connected with the passage of ice in some form which was partial and selective, impinging on all surfaces which were exposed to its movement from the N. and N.E., but which admitted of its passing entirely over, without any contact, all other surfaces which were not so exposed.

The evidence, therefore, in favour of the action of floating ice in a glacial sea grounding upon and grinding over the rocks and shoals of a rising and emerging land, is accumulative evidence, including a great variety of corroborating details. Moreover, it is evidence which, so far as I can see, is of such a nature as to exclude the possibility of the action of other forms of ice, such as have been suggested in either local glaciers or in an ice sheet.

I do not deny, nor do I seek to minimise, the great difficulties presented by this explanation of a very peculiar set of facts. It involves the idea of a submergence of the land, and a re-emergence of it, at some time so recent that in all its main contours or outlines the country was very much as we see it now. But the difficulty of conceiving such an operation, or rather the difficulty of accounting for it by any known physical causes, must not lead us to hesitate in accepting evidence which in itself admits of no other explanation. We have to recollect, too, that at least one other explanation, namely, that of an ice sheet moving over the whole country, besides failing to account for the facts, involves physical difficulties of a much more formidable nature. The supposed cause of motion in such a body of ice has never been explained. I believe it to be a physical impossibility. This cannot be said of the forces which we must believe have acted on the elevation of our existing islands and continents. They have been undoubtedly such as are capable of reproducing like effects at any time. We are, no doubt, accustomed to assume that these earth-movements have been sleeping for a far longer time, and that, when they did act, they always acted with infinitesimal slowness in time and in effects. But this is an assumption in which, very possibly, we may be entirely mistaken; and we have to consider the significant fact that one of the most experienced and most cautious of our eminent geologists, Professor Prestwich, has very recently been led to the opinion that some comparatively sudden submergence, and some correspondingly rapid re-elevation of the land, has left clear evidence of its occurrence all over the south of Europe, at a date quite recent in geological time.

THE DUKE OF ARGYLL ON TWO GLENS (GLEN ARAY & GLEN SHIRA) AND THE AGENCY OF GLACIATION.

SCALE OF COLOURS

OROGRAPHICAL COLOURING

2750 TO 2500
2500 TO 2250
2250 TO 2000
2000 TO 1750
1750 TO 1500
1500 TO 1250
1250 TO 1000
1000 TO 750
750 TO 500
500 TO 250
250 TO SEA LEVEL

Contours are drawn at intervals of 250 feet and tinted according to Height.

BATHYGRAPHICAL COLOURING

Low Tide TO 5
5 TO 10
10 TO 20
20 TO 30
30 TO 50
50 TO 100
100 TO 500

Contours showing Depth in Fathoms

Edinburgh Geographical Institute

Scale 2 Miles to an Inch

0 1 2 3 4 5

J.G.Bartholomew

V.—*On the Fossil Flora of the Yorkshire Coal Field.* (First Paper.)

By Robert Kidston, F.R.S.E., F.G.S. (Plates I.–III.)

(Read 15th July 1895.)

For many years the Fossil Flora of the Yorkshire Coal Field has been engaging my attention, and among the species occurring in that district are many of considerable interest. This Coal Field supplied Artis with the specimens which he figured and described in his *Antediluvian Phytology.**

In 1888, at the Annual Meeting of the Yorkshire Naturalists' Union, held at Malton, a committee was formed for the investigation of the Fossil Flora of Yorkshire, and since that date four Reports have been prepared and published based upon specimens submitted to me for examination by private collectors, and from collections contained in public museums.† These Reports only contain lists of the species found, and the localities and horizons from which the specimens were derived, with any occasional short notes that might have been thought necessary.‡ All detailed descriptions or critical remarks were deferred, and the present paper is the first of what I hope may be several, dealing more in detail with the Fossil Flora of the Yorkshire Coal Field.

Of the many species occurring in this area, none are more interesting than the *Filicites plumosus*, Artis, and the *Filicites Miltoni*, Artis; and to the consideration of the former of these two species the present paper is devoted.

Filicites plumosus, Artis, is an extremely variable species, and though this fern occurs in many of the British Coal Fields, and is frequent in the Upper and Middle Coal Measures, the greater portion of the specimens described and figured in this communication have been derived from the shales associated with the *Barnsley Thick Coal*, one of the seams of the Middle Coal Measures of Yorkshire, and which is on the *same horizon* as that from which the type specimen of Artis was derived at Elsecar, Yorkshire. It is chiefly for this latter reason that I deal so largely with Yorkshire

* *Antediluvian Phytology*, illustrated by a collection of the Fossil Remains of Plants peculiar to the Coal Formations of Great Britain. By Edmund Tyrell Artis, F.S.A., F.G.S., London. In all the copies I have seen, the Introduction to the work is dated 1st September 1825, but the title-page bears the date 1838. This latter date is evidently that of a later issue, or second edition of the work, and may only be an alteration of the title-page of the copies subsequently issued. Each of the twenty-four plates contained in the volume bears the date of 1824. That the work was issued at least ten years before 1838 is evidenced by the fact that Brongniart quotes the book in his *Prodrome d'une histoire des vegétaux fossiles*, published in Paris in 1828. Probably, therefore, 1825 is the true date for the first issue of the *Antediluvian Phytology*.

† The Yorkshire Carboniferous Flora—

First Report, *Trans. York. Nat. Union*, part xiv., 1890, pp. 1–64.
Second Report, „ „ part xviii., 1893, pp. 65–82.
Third Report, „ „ part xviii., 1893, pp. 83–96.
Fourth Report (with Index to the four Reports), part xviii., 1893, pp. 97–127.

‡ The names of those to whom the Committee were indebted for assistance are given in these Reports. I am however, almost entirely indebted to Mr W. Hemingway for my fine series of Yorkshire specimens of *Dactylotheca plumosa*, Artis, sp., from which largely the present paper has been written.

specimens in treating of this species, though the *Radstock Series* of the Upper Coal Measures, Somerset, have yielded me my largest and finest barren specimens.

It is not necessary here to enter into the geology of the Yorkshire Coal Field. This has been fully done in the *Geology of the Yorkshire Coal Field*,* and in other works dealing with this subject. It may be simply noted that probably all the divisions of the Coal Measures are present in this Coal Field,—the Upper, the Middle, and the Lower Coal Measures, but the Upper Coal Measures are only represented by "*Red Beds*," from which I have not yet seen any specimens, though I believe some plant remains have been found in them at Conisborough Pottery.†

The Middle and Lower Coal Measures contain all the workable seams in this Coal Field, but the great coal-yielding series of the Yorkshire Coal Field is the Middle Coal Measures.

The Coal Measures are largely worked in that portion of the county which lies around Halifax, Bradford, and Leeds, and which extends southwards to the neighbourhood of Sheffield.

In 1886‡ I united *Dactylotheca* (*Pecopteris*) *dentata*, Brongt., with *Dactylotheca* (*Pecopteris*) *plumosa*, Artis, sp., while preparing the Catalogue of the Palæozoic Plants in the British Museum, and I firmly held this opinion till about three years ago, when some specimens submitted to me from Yorkshire led me to believe that *Pecopteris dentata*, Brongt., was specifically distinct from *Pecopteris plumosa*, Artis, sp. §

This latter opinion I saw, very shortly after, full cause to reject; and the points connected with the fructification, on which I thought the species might be separated, and to which I shall more fully refer, were found to be entirely dependent on the position of the fruiting portions on the frond and their state or condition of development.

On the three plates accompanying this paper, figures are given of the typical plant as well as of a number of forms of *Dactylotheca plumosa*, Artis, sp., to which specific names have in some cases been given. It is an extremely variable species,—the extreme forms differing so much in appearance that they have given rise to the creation of several supposed species, all of which, when one has the opportunity of studying a large series of specimens, are shown to pass into each other by insensible gradations, and which seem to represent only different portions of what must have been a very large frond.

I have therefore found it quite impossible to draw any line of demarcation between what might appear at first sight such distinct forms as *Sphenopteris crenata*, L. and H., on the one hand, and *Pecopteris dentata*, Brongt., on the other. In fact, these differences seem to depend in great measure on whether the fragment is barren or fruiting, and on the position it held on the frond of which it originally formed a part.

Several of the species here placed under the name of *Dactylotheca plumosa*, Artis, sp.,

* *Memoirs of the Geological Survey of England and Wales.* By A. H. Green, R. Russell, &c. London, 1878.

† See Kidston, "On the Various Divisions of British Carboniferous Rocks as determined by their Fossil Flora," *Proc. Roy. Phys. Soc. Edin.*, vol. xii. p. 210, 1894.

‡ *Catal. Palæoz. Plants*, p. 128.

§ *Trans. York. Nat. Union*, part xviii. p. 106, 1893.

have been previously united with one or other of the species I regard as synonymous with the Yorkshire plant :—

Dactylotheca, Zeiller, 1883.

1883. *Dactylotheca*, Zeiller. *Ann. d. Scienc. Nat.*, 6e. sér., 'Bot.', vol. xvi. pp. 184 and 207, pl. ix. figs. 12–15.
1888. *Dactylotheca*, Zeiller. *Flore foss. Bassin houil. d. Valenciennes*, p. 30, fig. 16.
1891. *Dactylotheca*, Kidston. *Trans. Geol. Soc. Glasgow*, vol. ix. p. 27, pl. ii. fig. 26.
1877. *Senftenbergia*, Stur. (*not* Corda) (*in part*), *Culm Flora*, vol. ii. p. 187.
1883. *Senftenbergia*, Stur. (*not* Corda) (*in part*), *Zur. Morph. u. Syst. d. Culm u. Carbonfarne*, p. 33 (in *Sitzb. d. k. Akad. d. Wissensch.*, vol. lxxxviii. Heft i. p. 665).

Generic description.—Sporangia exannulate, oval or oval acute, formed of elongated thick-walled cells, and attached to the secondary veins a little above their point of origin.

Remarks.—The first description of the fruit of *Pecopteris dentata*, Brongt. (= *Pec. plumosa*, Artis, sp.), is that given by Zeiller in 1880,* but he did not till 1883 create the genus *Dactylotheca* for the reception of this species.

In 1877 Stur included *Pecopteris dentata* in the genus *Senftenbergia*, Corda,† but this is clearly an error, for the chief characteristic of the genus *Senftenbergia* is the presence of a very prominent apical annulus, whereas the sporangia of *Dactylotheca* are absolutely devoid of any annulus, even in its most rudimentary form.

Mons. Zeiller has detected a longitudinal band of narrower cells in the direction in which the sporangia appear to have opened at maturity. This longitudinal band I have not observed on my specimens, but it can only be seen in one position of the sporangia.

Dactylotheca is *Marattaceous*, and amongst recent ferns finds its nearest ally in *Angiopteris*.

Dactylotheca plumosa, Artis, sp.

Pls. I.–III.

1886. *Dactylotheca plumosa*, Kidston. *Catal. Palæoz. Plants*, p. 128.
1890. „ „ „ *Trans. York. Nat. Union*, part xiv. p. 36.
1825. *Filicites plumosus*, Artis. *Antedil. Phytol.*, p. 17, pl. xvii.
1828. *Pecopteris plumosa*, Brongt. *Prodrome*, p. 58.
1836. „ „ „ *Hist. d. végét. foss.*, p. 348, pls. cxxi.–cxxii.
1869. „ „ Roehl. *Foss. Flora d. Steink. Form. Westph.*, p. 88, pl. xxvii. fig. 4.
1877. *Senftenbergia plumosa*, Stur. *Culm Flora*, Heft ii. p. 187 (293).
1883. „ „ „ *Morph. u. Syst. d. Culm u. Carbonfarne*, p. 44.‡
1885. „ „ „ *Carbon-Flora*, I. *Farne d. Carbon-Flora d. Schatzlarer Schichten.*, p. 92, pl. li. figs. 1–3.
1828. *Pecopteris dentata*, Brongt. *Prodrome*, p. 58.

* *Végét. foss. du terr. houil.*, p. 87.
† Corda, *Beitr. z. Flora d. Vorwelt.*, p. 91, pl. lvii. figs. 1–6, 1867.
‡ *Sitzb. d. k. z. Akad. d. Wissensch.*, vol. lxxxviii. Abth. i. p. 633.

1835. *Pecopteris dentata*, L. and H. *Fossil Flora*, vol. ii. p. 201, pl. cliv.
1836. „ „ Brongt. *Hist. d. végét. foss.*, p. 346, pls. cxxiii.–cxxiv.
1838. „ „ Presl in Sternb. *Vers.* ii. p. 152.
1869. „ „ Schimper. *Traité d. paléont. végét.*, vol. i. p. 508.
1879. „ „ Lesqx. *Coal Flora*, vol. i. p. 240, pl. xliv. fig. 4 (?).
1880. „ „ Zeiller. *Végét. foss. d. terr. houil.*, p. 87, pl. clxviii. figs. 3–4.
1882. „ „ „ *Flore houil. des. Asturies*, p. 14.*
1883. „ „ Renault. *Cours. d. botan. foss.*, vol. iii. p. 121, pl. xxi. figs. 4–5.
1855. *Cyatheites dentatus*, Geinitz (*in part*). *Vers. d. Steinkf. in Sachsen.*, p. 26, pl. xxix. figs. 10, 12; pl. xxx. fig. 2.
1869. „ „ Roehl. *Foss. Flora d. Steink. Form. Westph.*, p. 87, pl. xxvii. fig. 6.
1869. *Cyathocarpus dentatus*, Weiss. *Flora d. jüngst. Stk. u. Rothl.*, p. 86.
1877. *Senftenbergia dentata*, Stur. *Culm Flora*, Heft ii. p. 187 (293).
1883. *Dactylotheca dentata*, Zeiller. *Ann. d. Scienc. Nat.*. 6e. sér., 'Bot.', vol. xvi. pp. 184, 207, pl. ix. figs. 12–15.
1883. „ „ „ *Bull. Soc. Géol. d. France*, 3e. sér., vol. xii. p. 201.
1886. *Pecopteris* (*Dactylotheca*) *dentata*, Zeiller. *Flore foss. Bassin houil. d. Valenciennes*, p. 196 (1888), pls. xxvi. figs. 1–2; xxvii. figs. 1–4; xxviii. figs. 4–5.
1892. „ „ *dentata*, var. *obscura*, Zeiller. *Bassin. houil. et perm. de Brive.*, fasc. ii.; *Flore foss.*, p. 26, pl. ii. figs. 1–5.
1828. *Pecopteris triangularis*, Brongt. *Prodrome*, p. 58.
1832. *Sphenopteris caudata*, L. and H. *Fossil Flora*, vol. i. p. 137, pl. xlviii.; vol. ii. p. 157, pl. cxxxviii.
1836. *Aspidites caudatus*, Göpp. *Syst. fil. foss.*, p. 363.
1845. *Pecopteris caudata*, Unger. *Synop. plant foss.*, p. 97.
1834. *Pecopteris serra*, L. and H. *Fossil Flora*, vol. ii. p. 71, pl. cvii.
1838. „ „ Presl in Sternb. *Vers.* ii. p. 159.
1869. „ „ Schimper. *Traité d. paléont. végét.*, vol. i. p. 504.
1877. „ „ Lebour. *Illustr. of Fossil Plants*, p. 47, pl. xxiii.
1836. *Alethopteris serra*, Göpp. *Syst. fil. foss.*, p. 302.
1836. *Pecopteris delicatula*, Brongt. *Hist. d. végét. foss.*, p. 349, pl. cxvi. fig. 6.
1838. „ „ Presl in Sternb. *Vers.* ii. p. 157.
1869. „ „ Schimper. *Traité d. paléont. végét.*, vol. i. p. 510.
1848. *Cyatheites delicatulus*, Bronn. *Index palœont.*, p. 364.
1886. *Pecopteris* (*Dactylotheca*) *dentata*, var. *delicatula*, Zeiller. *Flore foss. Bassin houil. d. Valenciennes*, pl. xxviii. fig. 5, Text, p. 199, 1888.
1890. *Dactylotheca plumosa*, var. *delicatula*, Kidston. *Trans. York. Nat. Union*, part xiv. p. 36.
1838. *Pecopteris Brongniartiana*, Presl in Sternb. *Vers.* ii. p. 160.
1834. *Sphenopteris crenata*, L. and H. *Fossil Flora*, vol. i. p. 57, pls. c.–ci.
1869. „ „ Schimper. *Traité d. paléont. végét.*, vol. i. p. 379.
1890. „ „ Kidston. *Trans. York. Nat. Union*, part xiv. p. 30.
1836. *Cheilanthites crenatus*, Göpp. *Syst. fil. foss.*, p. 248.
1883. *Senftenbergia crenata*, Stur. *Morph. u. Syst. d. Culm u. Carbonfarne*, p. 44.
1885. „ „ „ *Carbon-Flora*, I. *Die Farne d. Carbon-Flora d. Schatzlarer Schichten*, p. 72 (pls. xlv. figs. 1, 2, and 3, *figures very indistinct*).
1834. *Schizopteris adnascens*, L. and H. *Fossil Flora*, vol. i. p. 58, pls. c.–ci.
1836. *Trichomanites adnascens*, Göpp. *Syst. fil. foss.*, p. 266.
1838. *Aphlebia adnascens*, Presl in Sternb. *Vers.* ii. p. 113.
1869. *Rhacophyllum adnascens*, Schimper. *Traité d. paléont. végét.*, vol. i. p. 686, pl. xlviii. figs. 1–2 (*fig.* 7 (?)).
1836. *Aspidites silesiacus*, Göpp. *Syst. fil. foss.*, p. 364, pl. xxvii. (pl. xxxix. fig. 1. (?)).
1869. *Pecopteris silesiacus*, Schimper. *Traité d. paléont. végét.*, vol. i. p. 517.

* *Mém. Soc. Géol. du Nord.* Lille, 1882.

1877. *Pecopteris silesiaca*, var. Lebour. *Illustr. of Fossil Plants*, p. 53, pl. xxvi.
1838. *Steffensia silesiaca*, Presl in Sternb. *Vers.* ii. p. 122.
1854. *Pecopteris Glockeriana*, Ett. (Göpp. (?)). *Steinkf. v. Radnitz.*, p. 44, pl. xvii. fig. 1.
1854. *Pecopteris angustifida*, Ett. *Steinkf. v. Radnitz.*, p. 45, pl. xvi. fig. 1.

Description.—Frond very large, much divided, tripinnate or quadripinnate. Pinnæ alternate. Primary pinna broadly lanceolate. Secondary pinnæ lanceolate or linear-lanceolate, often slightly overlapping, the central portion the widest, ending in a sharp point and slightly narrowed at the base; the central portion often of about equal width for $\frac{1}{3}$ of the length of the pinna. Tertiary pinnæ linear-lanceolate, tapering to a bluntish apex, the basal portion being usually the broadest. The lower portion of the frond probably becomes quadripinnate. The large pinnæ are subtended by two stipular-like Aphlebia which spring from the anterior and posterior sides of the rachis. These are adpressed to the rachis, but, being directed upwards and outwards laterally, hold between them the base of the pinna they subtend. In general outline they are deltoid or sub-orbicular, and are composed of narrow much divided sharp-pointed linear segments without any apparent nervation.

Pinnules alternate, and varying much in form, size, and pinnule cutting, according to the position they hold on the frond being entire, dentate, or divided into teeth-like lobes.

The pinnules on the middle tertiary pinnæ are oval, triangular, or broadly lanceolate, with rounded apices, united by their whole base to the rachis. The basal inferior pinnule is deltoid—rounded, generally smaller than the others, and occupies the angle formed by the insertion of the rachis of the pinna with its parent stem; it bears a distinctly marked lobe on the margin next to the parent rachis. The basal superior pinnule is oval or oval-oblong, obtuse, and is the largest pinnule on the pinna. The upper pinnules become gradually united in their basal portions and form a more or less lobed, —and finally, an entire blunt apex to the pinna. As the pinnæ are traced upwards, through the union of pinnules amongst themselves, the pinnæ become simply lobed or dentate, and in some cases assume the form of oblong or linear entire pinnules. As the pinnæ are traced downwards towards the base of the frond, the pinnules on the tertiary pinnæ become more and more distinctly lobed, till they almost assume the form of small quadripinnate pinnæ.

The lateral veins in the basal pinnules of the lower tertiary pinnæ are generally once divided,—in the pinnules of the upper portion, the veins are usually simple; frequently, in the same pinnule, the lower lateral veins are divided, while the upper are simple. In the dentate pinnules usually each lobe has a bifurcated veinlet, and in the toothed pinnules of the lower pinnæ a simple vein runs into each tooth.

The *fructification* consists of exannulate oval or oval-acute sporangia, varying in length from ·50 mm. to ·65 mm., and formed of coriaceous elongated cells. The sporangia are placed upon, and parallel with, the lateral veinlets at a short distance above their point of origin. Frequently the sporangia occupy the whole of the space between the midrib and the margin of the pinnule. When the fructification is copiously

produced, it results in a partial reduction of the limb of the pinnule. Upper portion of the fructifying pinnæ barren.

Rachis rough, with small points from which caducous scales have fallen.

Remarks.—The fronds of *Dactylotheca plumosa*, Artis, sp., must have attained to a large size. I possess a specimen from Radstock, showing portions of two primary (?) pinnæ, neither of which is complete, but the most perfect, though it neither shows base nor apex, is about $16\frac{1}{2}$ inches long, and has a width of 12 inches, though even here the extremities of all the lateral pinnæ are broken off. Its complete width could not have been less than 18 inches, and was possibly greater. On fronds of this size the pinnule cutting must have varied greatly according to the position held by the pinnules on the frond.

The figures which accompany this communication better illustrate the various forms of pinnule cutting than could be conveyed by words. From simple pinnules, to others divided into sharp tooth-like lobes, all intermediate forms occur, which graduate into each other by insensible transitions. On some specimens, the simple undivided pinnule is found associated with those divided into prominent saw-like teeth.

To these polymorphous forms, many specific names have been given, and this is more fully referred to in the description of the specimens figured on the plates.

That these so-called species are only different portions of the same plant—and might equally well be fragments of the same frond—will, I believe, be admitted by anyone who has had the opportunity of examining such a large and fine series of specimens of *Dactylotheca plumosa*, Artis, sp., which it has been my good fortune to meet with.

These various forms cannot even consistently be described as varieties, for they only represent different portions and conditions of development—barren and fruiting—of the same frond; but should it be thought desirable to distinguish the particular form found at any given locality, it can easily be done by indicating the various forms, as *forma* crenata, *forma* caudata, &c.

Notes on Specimens figured by various Authors.

Filicites plumosus, Artis. *Antediluvian Phytology*, p. 17, pl. xvii.

Artis, like many of the older and, unfortunately, like some much more recent writers on Fossil Botany, gives no enlarged drawings of the details of the pinnule cutting and nervation of his *Filicites plumosus*, and his description is very meagre. Probably, this has contributed to the imperfect manner in which this fern is understood. Of the small portion of the fruiting specimen shown on the upper left-hand corner of his plate, he says, "Fructification near the margin of the leaflet." This appearance is only shown on imperfectly preserved specimens, of which I possess some similarly preserved from Cooper's Colliery, Worsborough Dale, near Barnsley,* to the small fragment figured by Artis.

* Collected by Mr W. Hemingway. (Reg. No. 2094, &c.)

ZEILLER, in 1883,* in remarking on the polymorphic nature of *Pecopteris dentata*, points out that the *Pecopteris plumosa*, Brongt.,† was only a form of *Pecopteris dentata*, and that he was inclined to unite to the same species the *Pecopteris delicatula*, Brongt.‡ That BRONGNIART was correct in identifying and figuring the plants he named *Pec. plumosa* as ARTIS' species is beyond all doubt, and the union of BRONGNIART'S figures of *Pecopteris plumosa* with the same author's *Pecopteris dentata* must carry the *Filicites plumosus*, Artis, along with it. Mons. ZEILLER, however, appears to have had some doubt as to the correctness of BRONGNIART'S identification of his specimens with ARTIS' plant.

ZEILLER gives, under the name of *Pecopteris* (*Dactylotheca*) *dentata*, some excellent figures of *Filicites plumosus*, Artis, in his *Flore foss. Bassin houil. d. Valenciennes.* His fig. 2, pl. xxvi., is typical of the form originally described by ARTIS. His fig. 2, pl. xxvii., is also an excellent rendering of the same form, as also are his figs. 3–4 of the same plate. His fig. 2, pl. xxvii., corresponds to my fig. 1, pl. i.

Sphenopteris caudata, L. and H. *Fossil Flora*, pls. xlviii. and cxxxviii.

This species is only one of the many forms of *Dactylotheca plumosa.* I give an illustration of the same form on pl. i. fig. 3, from a specimen communicated to me by Mr JOHN WARD, Longton, from below the *New Mine Coal*, the uppermost seam of the Lower Coal Measures, Adderley Green, Staffordshire. I possess an identical form (No. 2108) from the Middle Coal Measures of Yorkshire, collected by Mr W. HEMINGWAY from the *Thick Coal* at Monckton Main Colliery, near Barnsley.

The other specimen of *Sphenopteris caudata* which forms the subject of LINDLEY and HUTTON'S pl. cxxxviii., is preserved in the Hutton Collection, Newcastle-on-Tyne. It is not in a good state of preservation, but is evidently the plant named *Pecopteris dentata* by BRONGNIART. The locality given for this specimen is subject to much doubt; it more probably came from the Somerset Coal Field, as the shale on which the fossil occurs agrees with that found in Somerset, but not with the shales which are found at Jarrow Colliery, from which the specimen is stated to have come.

Pecopteris serra (?), L. and H. *Illustrations of Fossil Plants.*
Edited by G. A. LEBOUR. Pl. xxiii.

The fossil shown here is a small fragment of *Dactylotheca plumosa*, with which *Pecopteris silesiaca*, Göpp., sp., the name inscribed in pencil on the original drawing, is synonymous.§

Cyatheites dentatus, Geinitz. *Vers. d. Steinkf. in Sachsen*, p. 26.

Of the various figures given by this author, some appear to be doubtfully referable to this species. On his pl. xxv. fig. 11, he shows a specimen with *Aphlebia* attached

* *Bull. Soc. Géol. d. France*, 3e sér., vol. xii. p. 201.
† *Hist. d. végét. foss.*, pls. cxxi., cxxii. ‡ *Ibid.*, p. 349, pl. cxvi., fig. 6.
§ See also Crépin, *Bull. Soc. Roy. Bot. Belgique*, vol. xx. part ii. p. 25, 1881.

to the main rachis. These *Aphlebia*, which GEINITZ identifies as *Schizopteris Gutbieriana*, Presl, differ considerably in the wide foliaceous expansion of the segments from any *Aphlebia* of *Dactylotheca plumosa* (=*D. dentata*) that I have hitherto seen. From this I am led to infer that probably the fern here figured by GEINITZ should not be identified with *Pec. dentata*.

Also his figures on pl. xxx. figs. 1, 3, and 4, if really referable to this species, are misleading and had better be excluded as references; and if his fig. 4 faithfully represents the original specimen it cannot be referred to *Pecopteris dentata*.

Schizopteris adnascens.

LESQUEREUX, in the *Coal Flora*, vol. i. p. 321, pl. lvii. figs. 9, 10, and 11, figures and describes some *Aphlebia* under the name of *Rhacophyllum adnascens*, L. and H. The specimens are, however, unassociated with the parent stem, and in this condition it appears to me unsafe to identify his specimens with those borne on the rachis of *Sphen. crenata*, L. and H., especially as his figures do not appear to represent a similar *Aphlebia*.

I also doubt the accuracy of the reference of the isolated fragment given by SCHIMPER in his *Traité d. paléont. végét.*, pl. xlviii. fig. 7, to the *Schizopteris adnascens*, L. and H.

It is also perhaps advisable to treat in the same way the specimens figured as *Schizopteris adnascens* by GEINITZ in his *Vers. d. Steinkf. in Sachsen*, p. 20, pl. xxv. figs. 7–9.

HEER figures certain ferns which he identifies as the *Cyatheites dentatus*, Brongt.* Possibly he may be correct in his identifications, but if so, the figures are not satisfactory.

FONTAINE and WHITE, in their *Perm. and Upper Carb. Flora of West Virginia and S. W. Pennsylvania*, p. 66, pl. xxii. figs. 1–5 (1880), figure and describe a fern they refer to *Pec. dentata*, Brongt. The figures 1, 2, and 4 they provisionally name var. *crenata*, and their fig. 2 var. *parva*. Their plant, though having some of the characters of *Pecopteris dentata*, Brongt., does not seem to agree well with that species. I have not seen any original specimens of their plant, and therefore do not feel justified in expressing any definite opinion on its relationship to *Pecopteris dentata*, Brongt.

Aspidites silesiacus, Göpp. *Syst. fil. foss.*, p. 364, pl. xxvii.

The fine specimen figured by GÖPPERT on his pl. xxvii. is quite indistinguishable from *Dactylotheca plumosa*, Artis, sp. I possess a specimen of GÖPPERT's plant from Waldenburg, the original locality for *Aspidites silesiacus*, which was sent to me some years ago by the late Dr WEISS. One of the examples on this specimen completely agrees with the form of the plant given on my pl. ii. fig. 9, while another is similar to that shown on my pl. iii. fig. 12. The figure given by ZEILLER in the *Flore foss. Bassin houil. d. Valenciennes*, pl. xxvi. fig. 2, appears to me to be similar to GÖPPERT's *Aspidites*

* *Flore foss. Helv.*, Lief. i. p. 30, pls. xi. and xii. figs. 1–5, 1876.

silesiacus according to my specimen from Waldenburg. The enlargements given by GÖPPERT fully confirm the identity of his species with *Dactylotheca plumosa*. His figs. 2, 3, and 4 correspond to the plant given on my pl. iii. fig. 12, which is a common form in Britain, intermediate in character between *Filicites plumosus*, Artis, and *Sphenopteris crenata*, L. and H. The lower part of GÖPPERT's example is quite typical, *Sphenopteris crenata*, L. and H., and the upper part cannot be distinguished from *Pec. plumosa*, Artis, sp.

Again GÖPPERT's figs. 6 and 7, especially his fig. 6, has a great similarity to the *Sphenopteris caudata*, L. and H., which is seen in my pl. i. fig. 3.

The fructification of GÖPPERT's specimen has apparently been imperfectly preserved. The only remark he makes about it is that the sori (*Fruchthaüfchen*) are borne on the middle of the straight lateral nerves. No description of the *sporangia* is given.

GÖPPERT's second specimen, given on pl. xxxix. fig. 1, is too indistinct for criticism.

The *Pecopteris silesiaca*, Lebour. Illustrations of Fossil Plants, is the form named *Sphenopteris crenata*, L. and H., and is seen in my pl. iii. fig. 11, and in the lower portion of fig. 13.

The *Aspidites Glockeri*, Göpp.,* and var. *falcatus*, Göpp.,† may very possibly belong to the *Dactylotheca plumosa*, and SCHIMPER unites the type with *Pecopteris silesiacus*.‡ Whatever opinion may be held of the specific value of GÖPPERT's original specimens of *Aspidites Glockeri*, I cannot see how it is possible to regard the fern figured by ETTINGSHAUSEN as *Pecopteris Glockeriana* in his *Steinkf. v. Radnitz.*, pl. xvii. fig. 1, as other than *Dactylotheca plumosa*, Artis, sp. It is to be regretted that ETTINGSHAUSEN has not given any enlarged figures of the pinnule cutting and nervation of his specimen, and the description he gives is partially adopted from GÖPPERT.

The *Pecopteris angustifida*, Ettingshausen, given on pl. xvi. fig. 1 of the same work, is evidently to be referred to *Dactylotheca plumosa*, and corresponds to the form shown on my pl. i. fig. 1, but his specimen is apparently imperfectly preserved.

Pecopteris (*Dactylotheca*) *dentata*, var. *obscura*, Zeiller. *Bassin houil. et perm. de Brive*, p. 26, pl. ii. figs. 1–5, 1892.

In describing this variety ZEILLER says: The chief differences between this variety and the type are that "the pinnules on the secondary middle pinnæ are slightly contracted at the base and more or less imbricated; the anterior margin of each pinnule is in part covered by the posterior margin of that which lies in front of it; and further, the medial nerve of each pinnule is clearly decurrent at the base, and the secondary nerves are almost buried in the parenchyma and difficult to discern."

"It is chiefly the two last mentioned characters—the decurrence of the medial

* *Syst. fil. foss.*, p. 375, pl. xxix. figs. 1–2.
† *Loc. cit.*, pl. xxix. figs. 3–4.
‡ *Traité d. paléont. végét.*, vol. i. p. 518.

nerve and the obscurity of the secondary veins—which distinguish this form from the normal plant. The fructification also differs very little, the limb of the fertile pinnæ and pinnules, at least on the fossil figured on pl. ii. fig. 2, is much more reduced than on the fructifying specimens which I have had from the Middle Coal Measures, but perhaps these differences depend simply on the degree of development, and possibly one should not attach too great an importance to them."

"The sporangia are coriaceous, without any trace of an *annulus*, they possess all the characters of the genus *Dactylotheca*, and they differ from the sporangia of normal *Pecopteris dentata* only in that they are broader and shorter, and, in consequence, less tapered,—they are also more numerous and more closely placed the one to the other, and they appear to be disposed without any order."

These differences, as suggested by ZEILLER, may only represent a greater advance in maturity or a greater development of sporangia. He further refers to a similar occurrence in many species of *Asplenium*, where, when the fructification is very much developed, they cover the whole of the lower surface of the limb.*

Probably some of my Yorkshire specimens belong to the same form, such as that from which the sporangia were drawn, shown on my pl. ii. fig. 14. Here the sporangia, from their number and close position to each other, appear as if placed without order. In my figure the rows marked a' and a'' probably represent the sporangia of one pinnule, and were borne on the secondary veins.

My fig. 2, pl. i., is apparently the barren condition of ZEILLER's var. *obscura*.

Corresponding with ZEILLER's figure of the var. *obscura* given on his pl. ii. fig. 2, is probably my fig. 7, pl. ii. This figure only shows a small portion of a fruiting specimen, which is the *Sphenopteris crenate*, L. and H., so far as the portion figured is concerned, but the upper barren portions of the pinnæ not shown in the figure, possess all the characters of *Dactylotheca plumosa*. They are quite similar to my fig. 13, pl. iii., only not in so good a state of preservation.

Pecopteris (*Dactylotheca*) *Gruneri*, Zeiller.

ZEILLER describes in his *Flore fossile: Études sur le terr. houil. de Comentry*,† a *Dactylotheca* under the name of *D. Gruneri*, of which he gives drawings of both the barren and fruiting condition.

This species is certainly very closely related to *Dactylotheca plumosa*, if really specifically distinct from it.

Comparing it to *Pecopteris dentata* (which is synonymous with *Pecopteris plumosa*), he says:—"*Pecopteris Gruneri*, when compared to the *Pecopteris dentata*, is distinguished by the thickness of its limb, by its pinnules less distinctly lobed, more rounded at the

* STERZEL, in *Die Flora des Rothliegenden im Plauenschen Grunde bei Dresden* (*Abhandl. d. k. Sax. Gesell. d. Wissen. Math. Phys. Cl.*, vol. xix., Leipzig, 1893), p. 37, pl. v. figs. 1–6, describes another variety of *Pec. dentata* under the name of var. *Saxonica*.

† Page 104, pl. x. figs. 1–2, 1888.

summit, and finally by the primary pinnæ being closer and narrower in regard to their length, and by the rachis being always smooth."

Without examining the original specimens, one is not warranted to propose the union of *Dactylotheca Gruneri* with *Dactylotheca plumosa*; but in this last mentioned species the pinnules are entire, dentate, or lobed, according to the position they hold on the frond, and the rachis, though typically rough with small points, is, on the specimen figured on my pl. ii. fig. 7, quite smooth on one part, whereas another portion bears the characteristic little points. On the smooth portions of this rachis the little points have probably been obliterated by pressure, but the same cause might have equally well removed all evidence of them from the whole of the rachis.

The *Pecopteris Bioti*, Brongt., as described and figured by ZEILLER in the same work, also seems to be very closely related to *Dactylotheca plumosa.**

Sphenopteris crenata, L. and H., and *Aspidites silesiacus*, Göpp.

STUR has expressed his opinion that *Sphen. crenata*, L. and H., is identical with *Aspidites silesiacus*, Göpp., in his paper entitled "*Momentaner Standpunkt meiner Kenntniss uber die Steinkohlenformation, Englands.*" †

That *Pecopteris dentata* belonged to *Pecopteris plumosa* was suspected by ROEMER when he wrote his *Beitr. z. geol. Kennt. des nordw. Harzgebirges* in 1860.‡

DESCRIPTION OF SPECIMENS OF *Dactylotheca plumosa*, Artis, sp., FIGURED IN THE ACCOMPANYING PLATES I.–III.§

Pl. I. figs. 1 and 1*a*.

Specimen from Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.‖

This may be regarded as the typical form of *Filicites plumosus*, Artis. The ultimate pinnæ are linear or linear-lanceolate, with alternate pinnules. The inferior basal pinnule is placed in the angle formed by the union of the rachis of the ultimate pinna with the stem from which it springs, and is always smaller than the immediately succeeding pinnules. On the lower pinnæ, it is generally composed of two lobes, the foremost of which is usually sub-triangular, blunt, large, and the other—that next the stem which bears the pinna—is rounded and slightly smaller. The corresponding pinnule on the upper pinnæ is sub-triangular and simple, and fills up the angle formed by the union of the rachis of the pinna to its parent rachis, being united by its base in part to both. The basal superior pinnule is large and usually slightly larger than any of the succeeding pinnules. It is oblong-lanceolate, with an acute or slightly rounded point. The

* *Loc. cit.*, p. 99, pl. ix. figs. 2–4.

† *Jahrb. d. k. k. geol., Reichsanst*, 1889, vol. xxxix. Heft i. p. 5.

‡ *Palæont*, vol. ix. p. 34, 1860.

§ I have figured small specimens, to enable me to give a greater number of forms.

‖ The same horizon as that from which the type of *Filicites plumosus* was derived.

pinnules are directed slightly forward, and are entire or slightly crenulate at the margin (fig. 1*a*). The pinnules are rarely free, being generally united below. The lateral veins of the lower pinnules usually divide once; those of the upper pinnules are simple. The degree of distinctness with which the veins are visible depends in great measure on the condition of preservation of the fossil, but they appear to have been somewhat immersed in the parenchyma of the limb.

Pl. I. figs. 2, 2*a*, and 2*b*.

From the same *Horizon* and *Locality* as fig. 1.

This specimen appears to be the same type as that figured by ZEILLER as var. *obscura*.* The pinnules are broader in proportion to their length, and placed close together; the anterior border of the pinnule in its lower portion has a tendency to overlap the posterior margin of the pinnule in front of it. The pinnules are oblong-triangular, with rounded apices (fig. 2*a*), or oblong-linear, with sharp points. Their form alters according to the position they hold on the pinna, and whether the pinnæ belong to a higher or lower portion of the frond. The lateral veins are simple or bifurcated, according to the position of the pinnules on the pinna. The superior and inferior basal pinnules (fig. 2*b*), in their position and shape, conform to the characteristics which mark the type.

Pl. I. figs. 3 and 3*a*.

From Adderley Green, near Longton, Staffordshire. *Horizon.*—Below the New Mine Coal, which is the uppermost seam in the Lower Coal Measures of the Potteries Coal Field.

This is the *Sphenopteris caudata*, L. and H. *Fossil Flora*, vol. i. pl. xlviii. The other specimen which they figure under the same name in vol. ii. pl. cxxxviii., is, I think, the *Pecopteris dentata*, Brongt., but the original, which is contained in the "Hutton Collection," is badly preserved.

The penultimate pinnæ are linear-lanceolate and slightly overlapping. The ultimate pinnæ are narrow linear-lanceolate, distant from each other, and especially so in the upper portion of the penultimate pinnæ.

The pinnules are sub-triangular, directed forwards, and united to each other below. The inferior basal pinnule is smaller than the superior basal one (fig. 3*a*), which is always the largest and longest on the pinna.

The form and direction of the pinnules give a saw-like appearance to the pinnæ. The nervation is not shown.†

Pl. I. figs. 4, 4*a*, and 4*b*.

From Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Shale over Barnsley Thick Coal. Middle Coal Measures.

This interesting specimen shows in the pinnæ of the upper portion the typical form of pinnule and nervation of *Filicites plumosus*. The lower pinnæ, on the other hand,

* *Bassin houil. et perm. de Brive.*, p. 26, pl. ii. figs. 1–5.

† My thanks are due to Mr JOHN WARD, Longton, for this specimen.

seem indistinguishable from *Asplenites ophiodermaticus* of GÖPPERT, as figured on his plate xvii. figs. 1–2.* My enlarged fig. 4*a* seems similar to his enlarged fig. 2. The ultimate pinnæ are linear, alternate; the pinnules are bluntly oval, or shortly pointed. The pinnules on the basal part of the pinnæ are almost upright on the rachis; those about two-thirds up, and above this point, are directed slightly forwards towards the apex of the pinnæ. The pinnules are very closely placed, and the anterior margin of the pinnule slightly overlaps the posterior margin of the pinnule in front of it. They are united to each other at their bases, and this united portion forms a narrow wing along the rachis. The posterior basal pinnule is smaller than the others, and occupies the angle caused by the union of the pinna and its parent rachis (fig. 4*a*); the superior basal pinnule is, on the other hand, the largest on the pinna. By a gradual diminution of the lobing as the pinnæ recede from the basal portion of the specimen towards the apex, we find the position of the compound pinnæ (*a*) (on fig. 4), taken by small simple pinnæ (*b*) (on fig. 4), bearing first lobed or dentate (*b'*), and then entire pinnules (fig. 4*b*), having all the characters of typical *Filicites plumosus*. These upper pinnules are homologous with the ultimate pinnæ of the lower part of the specimen. The rachis is rough.

STUR,† among other species, unites with *Asplenites ophiodermaticus*, the *Sphenopteris caudata*, L. and H., pl. xlviii. This last-mentioned plant is certainly to be referred to *Filicites plumosus*, and very probably so should GÖPPERT's *Asplenites ophiodermaticus*, but not having seen any authentic specimens of GÖPPERT's plant, I prefer, in the meantime, to leave the union of this plant with *Filicites plumosus* an open question.

Perhaps BRONGNIART's fig. 3, pl. cxxiii.,‡ is the same form of the species as that given here on my pl. i. fig. 4.

Pl. II. figs. 5, 5*a*, and 5*b*.

From Woolley Colliery, Darton, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

This specimen is the *Sphenopteris crenata*, L. and H. The fossil shows the upper surface of the frond, but, at parts where the carbonaceous film is removed, the fructification is very beautifully shown. The pinnules are divided into narrow obtuse teeth-like lobes, as seen in the enlarged fig. 5*a*, the nervation of which is obscure.

The sporangia are beautifully preserved; one is shown magnified 26 times at fig. 5*b*. They exhibit no indication of an annulus.

The sporangia are placed so close together on the pinnules that they seem to occupy the whole of the dorsal surface, and frequently the two halves of the pinnule are conduplicately bent upon each other, in which case it is impossible to discover the original position of the sporangia, but they appear to have been placed almost parallel with the veins. The sporangia are about 0·65 mm. in length.

* *Syst. fil. foss.*, p. 280, 1836.
† *Die Carbon-Flora d. Schatz. Schichten*, p. 78, 1885.
‡ *Hist. d. végét. foss.*

Pl. II. fig. 7.

From Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

The specimen shows portion of a primary (?) pinna, and the fragment preserved is 26 cm. long. The rachis at its thickest part is about 7 cm. broad.

At certain parts of the rachis the little rough points are almost entirely effaced—probably from pressure—which, at other portions, are distinctly preserved, and this shows how much the absence or presence of such characters depends on the condition of preservation.

The plant is the *Sphenopteris crenata*, L. and H., but is not so well preserved, as far as the lateral pinnæ are concerned, as those shown at figs. 5 and 13. The specimen is a fruiting one, of which only a portion is shown natural size. It is similar to the fossil given at fig. 13. The upper ultimate pinnæ (not shown in the figure) are barren, and bear simple pinnules, of which some have simple and others bifurcated veins, identical with those shown at fig. 1*a*, fig. 4*b*, and fig. 13*a*, and which are typical *Filicites plumosus*. It is, therefore, seen that under certain conditions, when the *sporangia* are copiously produced, it results in the limb of the pinnules being more or less reduced. In the case of fig. 5, and in certain of the pinnæ of figs. 7 and 13, the reduction of the limb has reduced the pinnules to narrow teeth-like lobes, leaving only that portion of the *limb* on which the *sporangia* themselves are placed. This example also shows very beautifully the *Aphlebia* (originally supposed by Lindley and Hutton to be a parasite, and named by them *Schizopteris adnascens*), arising from the rachis at the points where the pinnæ are given off.

Mons. Zeiller has shown,* from specimens collected at Larche, that the *Aphlebia* which occur on the rachis are disposed in pairs at the origin of the *Aphlebia* bearing pinnæ,—one on the anterior, and the other on the posterior face of the rachis. They may thus be compared to two wing-like structures that arise from the back and front of the rachis, and bending upwards and outwards embrace the base of the pinna they subtend between them.

The *Aphlebia* are bipinnately divided into sharp-pointed lanceolate segments.

Zeiller has observed a similar arrangement of the *Aphlebia* on *Diplothmema Zeilleri*, Stur.†

Pl. II. fig. 6.

From the same *Locality* and *Horizon* as the last.

This fossil shows an early state of development of several pinnæ,—what might be called the "*Spirorbis*" condition of the plant,—where the pinnæ are still spirally coiled. The *Aphlebia*, however, appear to be fully developed, and therefore probably acted as protective organs to the more tender and immature portions of the frond.

* *Bassin houil. et perm. de Brive.*, p. 26, pl. ii. figs. 3–4.

† *Flore foss. Bassin houil. d. Valenciennes*, pl. xvi. fig. 1.

Pl. III. fig. 10.

This example, from the Barnsley Thick Coal, near Barnsley, shows natural size some of the largest *Aphlebia* of *Filicites plumosus* which I have yet seen. Their surface is finely striated in the direction of growth, but there is no clear indication of any nervation.

Pl. III. figs. 13, 13*a*, 13*b*, and 13*c*.

From Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

This specimen combines in the same example the characters of *Sphenopteris crenata*, L. and H., and *Filicites plumosus*, Artis. The upper part is the *Filicites plumosus*, Artis (fig. 13*a*), while its lower portion is the *Sphenopteris crenata*, L. and H. (figs. 13*c* and 13*b*).

The fossil is a fruiting example; but as only the upper surface of the pinnules is exhibited, the presence of the sporangia are only shown indistinctly through the tissue of the pinnules. This example corresponds to one of the lateral pinnæ, the basal portions of which only are shown on pl. ii. fig. 7, but it is much better preserved in regard to the minute structure of the pinnules. Fig. 13*a* shows two pinnules from the upper barren pinnæ, which are entire with simple veins.

It cannot be doubted that these dentate pinnules are formed by a reduction of the tissue of the limb through the development of a copious fructification. Were the upper portion of this specimen separated from the lower part, the upper would, without doubt, be labelled *Pecopteris plumosa*, whilst the lower portion would be named *Sphenopteris crenata* by those who regard these two as distinct species. The rachis is roughened by the customary little points.

Pl. III. figs. 11, 11*a*, and 11*b*.

From Shropshire. Middle Coal Measures. (Exact *Locality* and *Horizon* unknown.)

This fossil is the *Sphenopteris crenata*, L. and H. On the other hand, it approaches somewhat, in the small lobes of the long narrow pinnules, to the *Sphenopteris caudata* of the same authors (vol. i. pl. xlviii.).* The specimen is well preserved and shows the nervation in some of the pinnules. In the basal lobes the vein bifurcates, or the lobe has a central vein giving off lateral branchlets (fig. 11*b*). In the upper lobes the veins are simple (fig. 11*a*). The specimen exhibits the upper surface of the frond, and shows no indication of bearing sporangia, though the form of the pinnules is that which is frequently associated with fructification in this species.

The basal pinnæ have six or seven pairs of rounded lobes and a long tapering blunt apical lobe (fig. 11*a*), but the upper pinnæ have only a few pairs of rounded lobes at their base, while the uppermost ones are entire.

Pl. III. figs. 12, 12*a*, and 12*b*.

From South Kirby Colliery, near Pontefract, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

* See also my fig. 3, pl. i.

This is one of those forms which stands intermediate in character between *Sphenopteris crenata*, L. and H., and *Pecopteris plumosa*, Artis, and which it is very difficult to refer to either one or the other, but, in its general aspect, it has perhaps a greater similarity to *Sphenopteris crenata*. The rachis is roughened with small points.

On the ultimate pinnæ the inferior basal pinnule is very small and composed of two lobes,—a larger subtriangular one, with a smaller lateral rounded lobe next to the main rachis. The basal superior pinnule is longer than the succeeding pinnules, and on the lower pinnæ bears several pairs of rounded lobes (fig. 12*b*). The corresponding pinnule on the upper pinnæ bears a few lobes at the base (fig. 12*a*). A central vein gives off lateral veinlets to each lobe.

Pl. II. fig. 14 × *28*.

From Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

This figure shows a few *sporangia* magnified 28 times, from another specimen belonging to the *Sphenopteris crenata form* of the same species. This specimen shows how the *sporangia* are placed on the pinnules. Each of the small lobes had a row on each margin, the sporangia lying at right angles to the midrib. Thus, in fig. 14, the central vein ran between the two rows marked a' and a'', but most probably the sporangia were placed on lateral veinlets, which sprang from this central vein, and which have now disappeared. I think this is shown from the nervation preserved in figs. 11*a* and 11*b*, pl. iii.

The sporangia drawn show some groups from which all trace of the limb has been removed, and which have probably adhered to the counterpart of the block containing the fossil, thus leaving only the sporangia attached to the matrix of the specimen in my possession.

The sporangia, which are beautifully preserved and show well the cell structure, are oval in form, and measure on an average about 0·50 mm. in length. They are absolutely devoid of all trace of an annulus. Had an annulus been present even in a most rudimentary form, from the excellent state of preservation of the sporangia on this and on several other examples in my possession, it could not have escaped observation.

The sporangia on all my specimens are more oval than those described by Zeiller in the *Flore foss. Bassin houil. de Valenciennes*, pl. xxvi. fig. 2, and in the *Ann. d. Scienc. Nat.*, 6ᵉ sér. 'Bot.', vol. xvi. pl. ix. figs. 12–15, 1883, but they agree in form with those of his *Dactylotheca dentata*, var. *obscura*.* The general character of Zeiller's fig. 2, pl. ii.,* in the copious manner in which the sporangia have been produced and the absence of the limb, shows a great resemblance to such specimens as those figured on my pl. ii. figs. 5, 7, and 14.

Pl. II. figs. 9, 9*a*, 9*b*, and 9*c*.

From Monckton Main Colliery, near Barnsley, Yorkshire. *Horizon.*—Barnsley Thick Coal. Middle Coal Measures.

* *Flore foss. Bassin houil. et perm. de Brive.*, p. 26, pl. ii. figs. 2, 2*a*, 2*b*, and 2*c*.

This example shows the arrangement of the sporangia on the pinnules. In this specimen the pinnules are oblong, obtuse, and entire, and placed close to each other. The nervation is obscure, but apparently the lateral veins have bifurcated, and each arm has borne a sporangium (figs. 9*a* and 9*b*). On these smaller pinnules the sporangia occupy the whole space between the midrib of the pinnule and its margin, and were parallel with the course of the lateral veinlets—in fact, were placed on them.

The sporangia are oval, but the apex is slightly more pointed than the base. They measure about 60 mm. long. Their walls are composed of elongated coriaceous cells without any indication of an annulus. Fig. 9*c* shows a sporangium magnified 25 times.

Pl. II. figs. 8 and 8*a*.

From the same *Locality* and *Horizon* as the last.

This small specimen shows the barren condition of the form usually associated with the name of *Pecopteris dentata*, Brongt., and is similar to that given by ZEILLER in his *Flore foss. Bassin houil. d. Valenciennes.*, pl. xxvi. fig. 1. The basal inferior pinnule is small and lobed, and occupies the angle formed by the union of the rachis with the parent stem. The superior basal pinnule is, on the other hand, the largest on the pinna. The nervation is not well shown, and seems to be immersed in the tissue of the pinnule. The rachis is rough.

SPECIMENS FROM COOPER'S COLLIERY, WORSBOROUGH, NEAR BARNSLEY, YORKSHIRE.

Horizon.—Barnsley Thick Coal. Middle Coal Measures (Reg. Nos. 2093–2100).

These specimens occur on a light grey coloured shale, but are not so well preserved as those already described. They exhibit a slightly larger form of the plant, and the sporangia are slightly longer and proportionally narrower than those shown in my figures. They are not, however, so sharply pointed as those given by ZEILLER in the original description of his genus *Dactylotheca*. It was upon these differences that I presumed that *Pecopteris plumosa* might be specifically distinct from *Pecopteris dentata*, but I have since seen that what I thought might prove a distinguishing character does not hold, as these slight variations in the size and form of the sporangia appear to depend on the position of the pinnules and pinnæ on the frond on which the sporangia occur.

DISTRIBUTION IN BRITAIN.

Dactylotheca plumosa occurs in the Upper, Middle, and Lower Coal Measures. It attained its maximum period of development in the Upper Coal Measures, and though less frequent in the Middle Coal Measures it is still comparatively common. In the Lower Coal Measures, however, it has all but disappeared, and from this division I only know of four specimens, two of which are those figured by LINDLEY and HUTTON,—one as *Sphenop-*

teris crenata (pl. xxxix.), and the other as *Sphenopteris caudata* (pl. xlviii.). The two remaining Lower Coal Measure examples are one from Fife and the other from the Potteries Coal Field, North Staffordshire (Pl. I. fig. 3.)

SCOTLAND.

Lower Coal Measures.

Fife :—

Locality.—East Wemyss. (*Forma crenata.*) (J. Kirkby.)
Horizon.—Lower Coxtool Coal.

ENGLAND.

Upper Coal Measures.

Somersetshire :—*

Localities.—Kilmersden Pit, near Radstock.
Braysdown Colliery, near Radstock.
Tyning Pit, Radstock.
Wellsway Pit, Radstock.
Upper Conygre Pit, Timsbury.
Lower Conygre Pit, Timsbury.
Old and New Pits, Camerton.
Horizon.—Radstock Series.

Middle Coal Measures.

Lancashire :—

Locality.—St Helens. (Rev. H. H. Higgins.)
Horizon.—Ravenhead Coals.
Locality.—Dixon Fold, Stoneclough, near Manchester. (J. W. Croston.)
Horizon.—A little above Doe Mine.
Locality.—Ashton, near Manchester. (Brongniart.)
Horizon.—(?).
Locality.—Oldham. (Brongniart.)
Horizon.—(?).
Locality.—Worsley.
Horizon.—Bassey Mine. (28 yds. above Ramshorn Mine.)
Locality.—Oldham Edge, Oldham. (J. Nield.)
Horizon.—" Forest bed." (16 yds. below Hollingworth Mine of Oldham.)

Derbyshire :—

Locality.—Claycross. (Rev. J. M. Mello.)
Horizon.—(?).

* The forma *dentata* is much more common than any other in the Upper Coal Measures.

South Staffordshire. (Dudley Coal Field) :—

Locality.—Doulton's Marl Pit, Netherton, near Dudley. (H. W. Hughes.)

Horizon.—Blue Measures. (6 ft. above Fire Clay Coal.)

Locality.—Russell's Hall, Dudley. (H. W. Hughes.)

Horizon.—Roof of Fire Clay Coal.

Yorkshire :—

Localities.—Monckton Main Colliery, near Barnsley. (*Type and forma dentata.*) (W. Hemingway.)

East Gawber Colliery, near Barnsley. (*Type and forma dentata and crenata.*) (W. Hemingway.)

Woolley Colliery, Darton, near Barnsley. (*Type and forma crenata.*) (W. Hemingway.)

Elsecar, Wentworth. (Type of Artis.)

Horizon.—Barnsley Thick Coal.

South Kirby Colliery, near Pontefract. (*Forma dentata and type.*) (W. Hemingway.)

Horizon.—Barnsley Thick Coal.

Locality.—Cooper's Colliery, Worsborough, near Barnsley. (W. Hemingway.)

Horizon.—Rock over Barnsley Thick Coal.

Locality.—Wheatley Wood Colliery, near Barnsley. (W. Hemingway.) (*Forma crenata.*)

Horizon.—Winter Coal.

Worcestershire :—*

Localities.—Railway Cutting, immediately west of Dowles, Railway Bridge, Forest of Wyre. (T. C. Cantrill.)

Horizon.—(?).

Cooper's Mill, Dowles Valley, Forest of Wyre. (T. C. Cantrill.)

Horizon.—(?).

Lower Coal Measures.

Durham :—

Localities.—Jarrow Colliery. (Type of *Sph. crenata*, L. and H., pl. xxxix., also of *Pec. caudata*, L. and H., pl. xlviii.).†

Horizon.—Bensham Seam.

North Staffordshire (Potteries Coal Field) :—

Localities.—Adderley Green, near Longton. (*Forma caudata.*) (J. Ward.)

Horizon.—Below the New Mine Coal.

* I have also seen the *crenata* form from the Forest of Wyre, but do not know the exact locality from which the specimen was collected.

† *Note.*—The other specimens of *Sphenopteris crenata*, L. and H. (pls. c.–ci.), came from the Whitehaven Coal Field, but I have hitherto been unable to visit this Coal Field, so can express no opinion as to their age.

EXPLANATION OF PLATES.

Plate I.

Fig. 1. *Dactylotheca plumosa* Artis, sp. (*Typical form*). *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector, Reg. No. 2107. See p. 213.

Fig. 1*a*. Two pinnules, × 4.

Fig. 2. *Dactylotheca plumosa*, Artis, sp. (*Pecopteris dentata*, Brongt.). *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 2112. See p. 214.

Fig. 2*a* and 2*b*. Pinnules, × 4.

Fig. 3. *Dactylotheca plumosa*, Artis, sp. (*Pecopteris caudata*, L. and H.). *Loc.* Adderley Green, near Longton, Staffordshire. *Hor.* Below New Mine Coal.—The uppermost seam in the Lower Coal Measures. Natural size. J. Ward, Collector. Reg. No. 357. See p. 214.

Fig. 3*a*. Pinnule, × 4.

Fig. 4. *Dactylotheca plumosa*, Artis, sp. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Shale over Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 2111. See p. 214.

Fig. 4*a*. Portion of pinna, × 4.

Plate II.

Fig. 5. *Dactylotheca plumosa*, Artis, sp. (*Sphenopteris crenata*, L. and H.). Fruiting specimen. *Loc.* Woolley Colliery, Darton, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 1215. See p. 215.

Fig. 5*a*. Pinnule, × 4.

Fig. 5*b*. Sporangium, × 26.

Fig. 6. *Dactylotheca plumosa*, Artis, sp. Circinately coiled up specimen showing the *Aphlebia*. (*Schizopteris adnascens*, L. and H.). *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 1212. See p. 216.

Fig. 7. *Dactylotheca plumosa*, Artis, sp. (*Sphenopteris crenata*, L. and H., and *Schizopteris adnascens*, L. and H.). Portion of a large specimen showing the *Aphlebia* attached to the rachis at the point of insertion of the pinnæ. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Main Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 1210. See p. 216.

Fig. 8. *Dactylotheca plumosa*, Artis, sp. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Meaaures. Natural size. W. Hemingway, Collector. Reg. No. 2105. See p. 219.

Fig. 9. *Dactylotheca plumosa*, Artis, sp. Fruiting specimen. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway Collector. Reg. No. 2088. See p. 218.

Fig. 9*a*. Two pinnules, showing the arrangement of the sporangia.

Fig. 9*b*. Another pinnule, showing the sporangia.

Fig. 9*c*. A sporangium, × 25.

Fig. 14. *Dactylotheca plumosa*, Artis, sp. Sporangia, × 28 from another specimen which shows the *Aphlebia* attached to the rachis. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. W. Hemingway, Collector. Reg. No. 2092. See p. 218.

Plate III.

Fig. 10. *Dactylotheca plumosa*, Artis, sp. *Aphlebia* (*Schizopteris adnascens*, L. and H.). *Loc.* Near Barnsley, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 2110. See p. 216.

Fig. 11. ***Dactylotheca plumosa***, Artis, sp. (*Sphenopteris crenata*, L. and H.). *Loc.* Shropshire. *Hor.* Middle Coal Measures. Natural size. Reg. No. 966. See p. 217.

Fig. 11*a*. **Ultimate pinna,** × 4.

Fig. 11*b*. **Two pinnules,** showing nervation more highly enlarged.

Fig. 12. ***Dactylotheca plumosa***, Artis, sp. (Approaching the form named *Sphenopteris crenata*, L. and H.). *Loc.* South **Kirby Colliery**, near Pontefract, Yorkshire. *Hor.* Barnsley Thick Coal. Middle Coal Measures. Natural size. **W. Hemingway**, Collector. Reg. No. 2109. See p. 217.

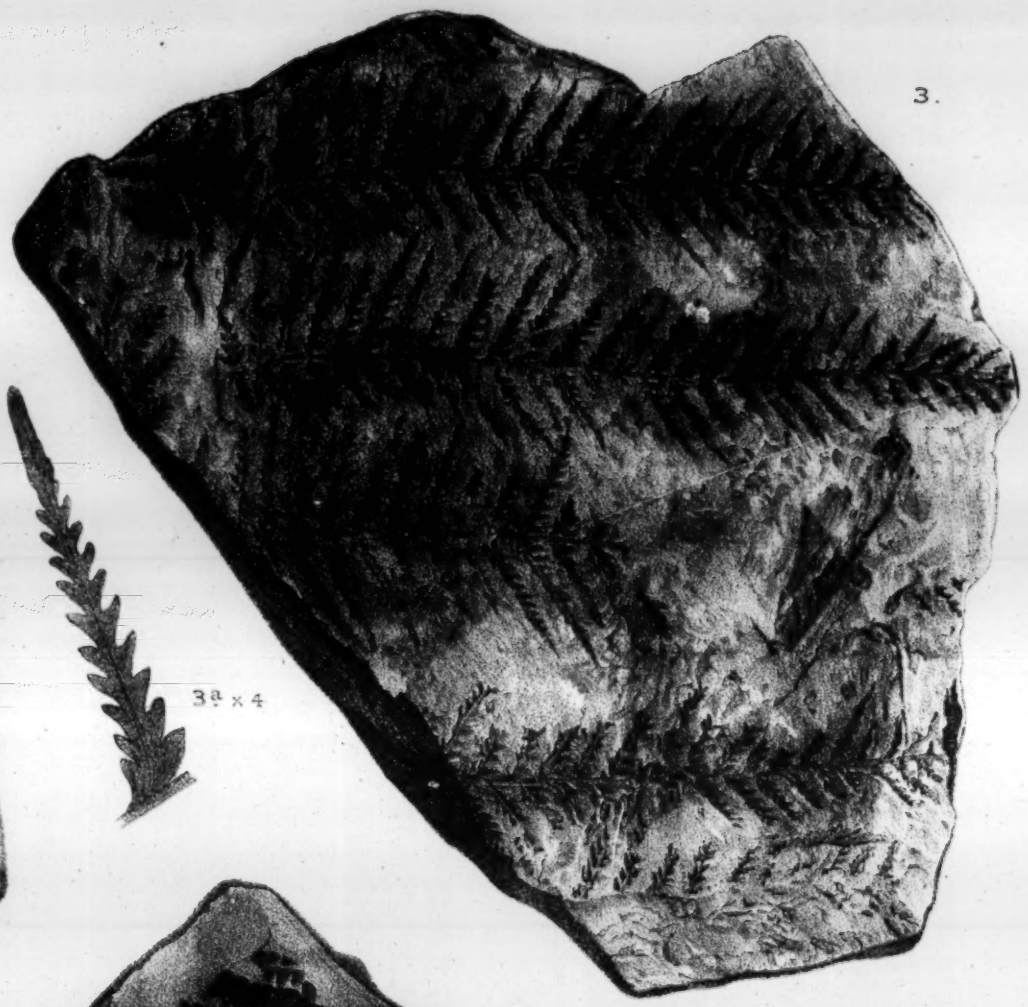
Fig. 13. ***Dactylotheca plumosa***, Artis, sp. Portion of a specimen, showing the organic union of typical "*Filicites plumosus*, **Artis,**" and *Sphenopteris crenata*, L. and H. *Loc.* Monckton Main Colliery, near Barnsley, Yorkshire. *Hor.* **Barnsley Thick** Coal. Middle Coal Measures. Natural size. W. Hemingway, Collector. Reg. No. 2101. **See p. 217.**

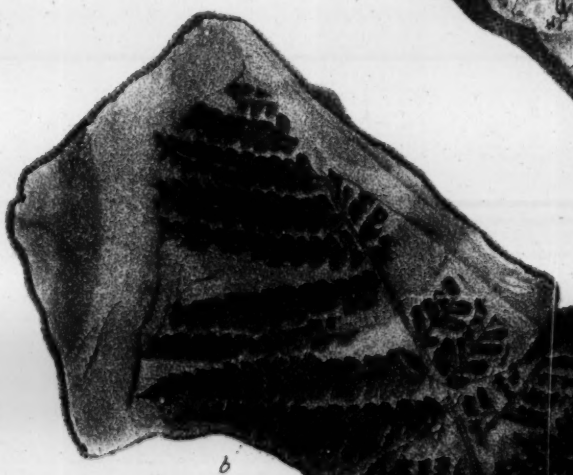
Fig. 13*a*. **Two pinnules** from the upper portion of the specimen corresponding to the "*Filicites plumosus*, Artis," × 4.

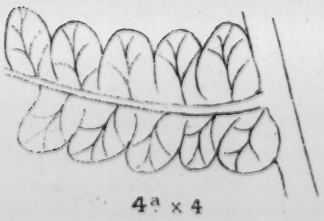
Figs. 13*b* and *c*. **Two pinnules** from a lower part of the specimen corresponding to the *Sphenopteris crenata*, L. and H.

Note.—All the figured specimens are in the author's collection.

KIDSTON, ON THE FOSSIL FLORA OF THE YORKSHIRE COAL FIELD. Pl. I.







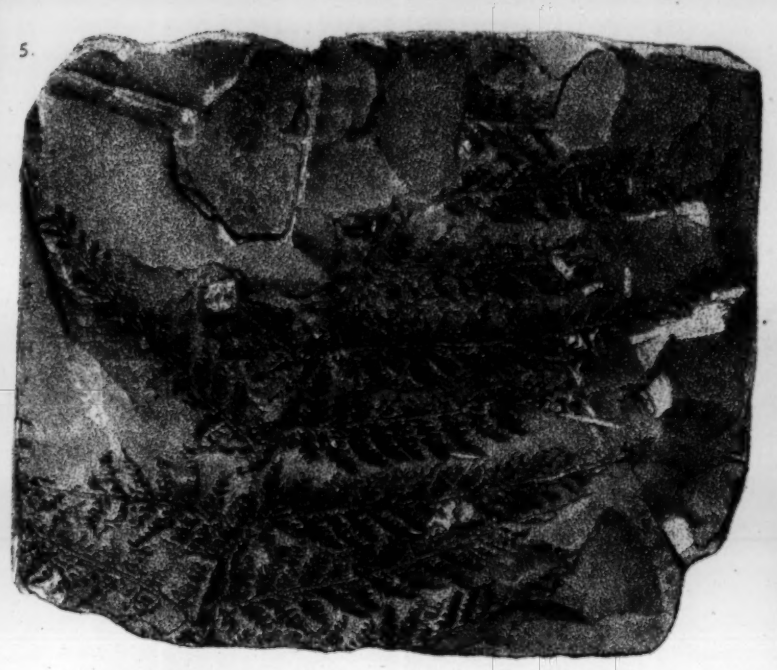
A. Kidston.

F. Huth, Lith.r Edin.r

DACTYLOTHECA PLUMOSA, Artis sp.

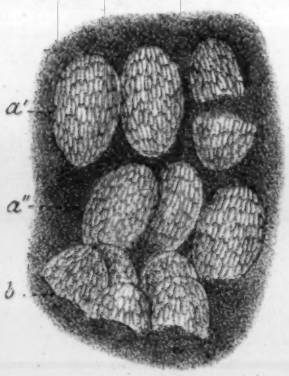
KIDSTON, ON THE FOSSIL FLORA OF THE YORKSHIRE COAL FIELD. Pl. II.

5.



7.

6.

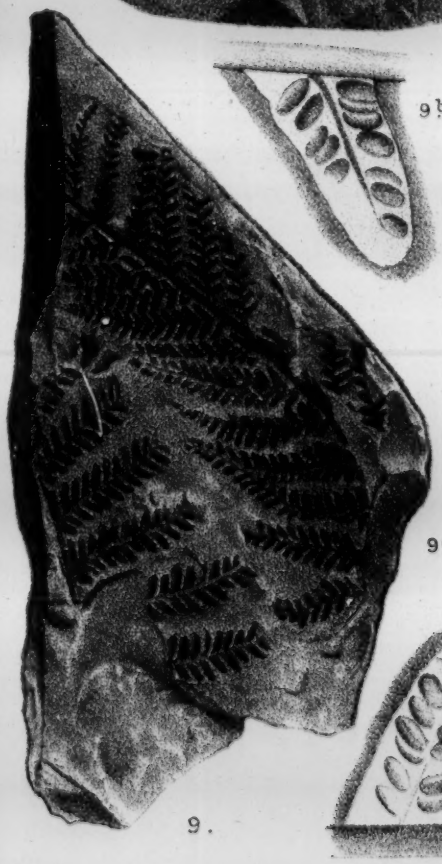


14 × 28

5b × 26

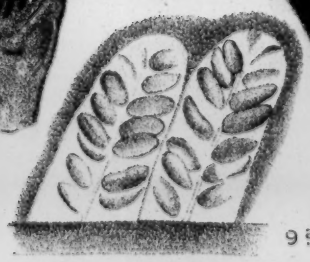
9b × 8

5a × 4



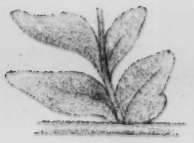
9.

9c × 25



9a × 8

8.



8a × 4

R. Kidston.

F. Huth. Lith.r Edin.r

DACTYLOTHECA PLUMOSA, Artis sp.

KIDSTON, ON THE FOSSIL FLORA OF THE YORKSHIRE COAL FIELD. Pl. III.

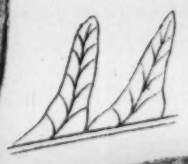
10.

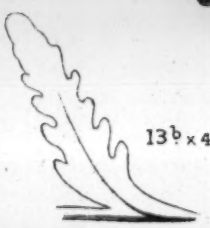
$11^a \times 4$

11^b

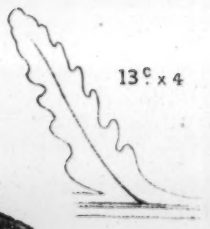
11.

$13^a \times 4$





$13^b \times 4$



$13^c \times 4$

$12^a \times 4$

12.

13.

$12^b \times 4$

R. Kidston.

F. Huth, Lith.r Edin.r

DACTYLOTHECA PLUMOSA, Artis sp.

VI.—*Experiments on the Transverse Effect and on some Related Actions in Bismuth.*

By **J. C. Beattie.** (With a Plate.)

(Read 17th December 1894.)

Section I.—Introduction.

Clerk Maxwell, in his *Electricity and Magnetism*, vol. i. § 304, makes the following remark about the rotatory coefficient :—"It should be found, if anywhere, in magnets which have a polarisation in one direction, probably due to a rotational phenomenon in the substance."

The current which should arise from such a coefficient was first observed by Hall. He passed a current through a strip of metal; he then found two points on opposite sides of the strip, which, while the current was flowing, were at the same potential, and which therefore indicated no current when joined to a galvanometer. The plate was next brought into a uniform magnetic field, and when everything was steady the two points previously at the same potential were no longer so, and a current flowed through the galvanometer. This effect is observable in all conductors.

Kundt * has shown that in iron, nickel, cobalt, it is proportional to the magnetisation. Whether this is true for the diamagnetic metals has not, so far as I know, been definitely settled yet. But, should this be proved, we have a comparatively easy method for studying the magnetisation in these metals.

Another phenomenon which may advantageously be studied by means of the transverse effect is the variation of resistance of conductors carrying a current in a magnetic field. Goldhammer † has shown in another way that the increase or decrease of the resistance in bismuth is proportional to the square of the magnetisation, and suggests that the same may be true for cobalt and nickel. Evidently the proportionality or non-proportionality for these two latter metals can be settled at once by comparing the variation of resistance and the transverse effect at the same field strength; and, similarly, the same method can be employed to show whether or not the variation of resistance bears any relation to the magnetisation in all cases where it has first been proved that the magnetisation and the transverse effect are proportional. So far as I know, this method has not as yet been tried experimentally. I propose in another paper to give some results relating to this matter.

In bismuth the transverse effect has not yet been proved to be proportional to the magnetisation; nor, indeed, is it certain that the so-called transverse effect in bismuth is a pure Hall effect, ‡ or is caused by a number of separate effects. As I shall show later, the transverse effect in most cases is really the sum of three effects.

* Wiedemann's *Annalen*, 1893, Bd. 49, S. 257. † Wiedemann's *Annalen*, 1889, Bd. 36.

‡ By Hall effect is meant a transverse effect proportional to the first power of the magnetisation. See "On Relation between the Variation of Resistance in Bismuth, &c.," *Trans. R.S.E.*, vol. xxxviii.

The following experiments were carried on in the Physicalisches Institut, Muenchen; and I have to thank Professor BOLTZMANN for the trouble he put himself to, for his suggestions, and for placing the whole resources of his laboratory at my disposal.

The plates used were cast from two separate quantities of ordinary mercantile bismuth. In some instances they were cooled quickly, in others slowly. The thicknesses varied from three to one millimetre; the ratio of length to breadth was about three to one as the plates were originally used; afterwards these dimensions were considerably modified.

The galvanometer used was a Wiedemann, with a Siemen's well-formed magnet.

The electro-magnet used for the creation of the magnetic field consisted of two cylinders of soft iron 60 cm. long, 16 cm. in diameter, placed on a parallelepiped of the same material 63 cm. long, 20 cm. high, 20 cm. broad. The shoes were formed by two blocks 16 cm. square, 20 cm. long, to which truncated cones were fixed with a base diameter of 16 cm., a summit diameter of 6 cm. Each cylinder was surrounded by two spools, round which the copper wires were wound. Diameter of the wire 2·5 mm.; the total length of wire was 3850 mm.; the number of windings 5951. (Cp. fig. A, Plate P.)

The current to the electro-magnet was supplied by an accumulator battery of 56 cells.

The strength of the field was measured by Verdet's method. A wire was arranged in the form of a square, the ends were inserted into the galvanometer circuit, and when the electro-magnet was on, the square which was kept perpendicular to the lines of force was pulled quickly out of the field.

The readings thus obtained were compared with those obtained from an earth inductor inserted in the same circuit, and the strength of the field in absolute units arrived at in the usual way. To get the strength of the field in absolute units, the numbers given as field strengths in the results must be multiplied by 138·5.

The strength of the current which flows in the direction of the plate's length—and which will be called the primary current—was measured at the beginning and end of each series of experiments. For this purpose a thick copper wire was inserted in the primary circuit. To two points of this, copper wires were soldered, which, by means of a commutator could be placed in the galvanometer circuit when necessary.

The electro-magnet was so placed that it exercised a minimum effect on the galvanometer, which was at a distance of thirty or forty feet. The magnet and primary currents could both be reversed by commutators; the number of readings necessary to eliminate disturbing effects was thus four. The average of the four readings was divided by the primary current strength: this quantity is called later the transverse effect.

The positive direction of the transverse effect is so defined: Let the plate of bismuth be supposed to be in the plane of the paper with the north pole of the magnet above, the south below, the paper. Then, if in going from the point where the primary current enters to that where the transverse current enters the motion is counter clock, we call the transverse effect positive.

In diagram B, Plate P, with dotted circle to represent north pole above the paper, the transverse effect is positive.

To both ends of the plates strips of copper of the same breadth and thickness were soldered; to these latter, wires were soldered, which lead to the accumulators giving the primary current.

To two points in the middle of the sides of the bismuth plates wires were soldered; each wire was doubled on itself, the point of contact with the bismuth forming the bottom of a V. Between the arms of the V mica was inserted to insure insulation. Both arms were kept in the plane of the bismuth plate and perpendicular to its length. One arm of each was joined to the galvanometer; the other led to a mercury pool in the first series of experiments, in the later ones it was unconnected. (Fig. C, Plate P.)

Section II.—On the Effect on the Transverse Current of Inserting a Shunt whose Resistance is of the same Order of Magnitude as that of the Plate.

The transverse effect has up till now always been measured with a galvanometer whose resistance was many times greater than that of the plate of metal experimented upon. The question arises, How will this current be affected when a shunt is inserted between the transverse electrodes whose resistance is of the same order of magnitude as that of the plate? If the plate when placed in a steady magnetic field behaves as a cell with constant electromotive force would do, it will divide according to Ohm's law; if, on the other hand, it behaves as a cell whose electromotive force is not constant, the current will not be obtainable from the equation—

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}.$$

For example, Prof. Lommel, in his paper "Sichtbare Darstellung der äquipotentialen Linien in durchströmten Platten. Erklärung des Hall'schen Phänomens,"* has proposed a formula, according to which the insertion of a shunt between the two transverse electrodes would not affect the reading on a galvanometer whose resistance is great—compared with the sum of the resistances of the bismuth plate and of this shunt.

Each plate experimented upon was placed between the poles of the electro-magnet, perpendicular to the lines of magnetic induction.

Before the magnet was put on, a current from the accumulators at A was sent through the plate. Two points, E and D, as near the middle as possible, were then found, so that when wires joined them to the galvanometer G, no current passed. From E and D two other wires lead to the mercury pools L and M respectively. Should it be found impossible to find two points at the same potential, the current which goes through the galvanometer circuit can be eliminated by joining E and N or D and N, as the case may be, and inserting a suitable resistance. (Cp. fig. D, Plate P.)

* *Sitzungsbericht der Köng. bayerischen Akedamie der Wissenchaft*, 1892, Bd. xxii. Heft iii. § 371.

A series of five experiments was made with each field strength. In 1st, 3rd, and 5th E L M D was open, in 2nd and 4th E L M D was closed.* The average of the first three was then divided by that of the 2nd and 4th.

Next, the resistance of the bismuth plate was measured when the electro-magnet was on. A current was sent by A in the direction A L E D M A, or *vice versâ*, and E and D were joined to the galvanometer; four readings were taken—the resistances of the copper wires L E, M D and of the short wire L M—the total being of the same order of magnitude as that of the bismuth plate. These measurements were made at the beginning and end of each series of five experiments.

Let C be the transverse current when E L M D is open, let S be the resistance of the shunt E L M D, n that of the bismuth plate. Then theoretically we have

$$\frac{\text{Current when E L M D is open}}{\text{Current when E L M D is closed}} = \frac{C}{\frac{c/n}{1/n + 1/s}} = 1 + \frac{n}{s}$$

But since we have measured n and s directly, we can calculate $1 + \frac{n}{s}$; the calculated and the observed values will agree, if the transverse effect is of the same nature as the current obtained from a cell of constant electromotive force.

The following are some of the results obtained:—

PLATE (Ia).

Length,	5·63	cm.
Breadth,	2·9525	„
Thickness,	0·19413	„

This plate was quickly cooled in casting; the temperature of the room was in all the experiments about 15° C. Made from first supply of bismuth.

Field Strength.	Trans. Current.	Shunted Trans. Current.	$\frac{\text{Trans. Current.}}{\text{Shunted Trans.}}$	$1 + \frac{n}{s}$ Calculated.
5·4	– 0·04412	– 0·030880	1·428	1·431
24·0	– 0·15364	– 0·10518	1·460	1·458
52·2	– 0·20186	– 0·13526	1·492	1·492
98·0	– 0·21016	– 0·1328	1·582	1·558
114·2	– 0·19179	– 0·12131	1·581	1·581
131·0	– 0·17829	– 0·11419	1·562	1·60

PLATE (Ib).

Length,	6·045	cm.
Breadth,	2·58	„
Thickness,	0·12235	„

Slowly cooled. Made from first supply of bismuth.

* The galvanometer reading obtained in this case, divided by the strength of the primary current, is called in the results the shunted transverse.

Feld Strength.	Trans. Current.	Shunted Trans. Current.	Trans. Current. / Shunted Trans.	$1+\frac{n}{s}$ Calculated.
118·0	– 0·14253	– 0·0666	2·138	2·118
140·0	– 0·20239	– 0·09329	2·169	2·150
148·0	– 0·22356	– 0·10174	2·197	2·159

PLATE II.

Length, ... 6·26 cm.
Breadth, ... 2·945 „
Thickness, ... 0·149725 „

Slowly cooled. Made from first supply of bismuth.

Field Strength.	Trans. Effect.	Trans. Effect with Shunt.	Trans. Effect. / Trans. Shunted.	$1+\frac{n}{s}$ Calculated.
36·0	– 0·19674	– 0·09929	1·981	1·947
61·0	– 0·25164	– 0·14596	1·724	1·76
120·0	– 0·30315	– 0·13744	2·203	2·186
137·8	– 0·30779	– 0·12963	2·374	2·357
146·0	– 0·31051	– 0·11821	2·626	2·489

The dimensions of the plate were next altered; in particular the thickness was considerably reduced by planing. It was now

0·0827 cm.

Field Strength.	Trans. Effect.	Trans. Effect with Shunt.	Trans. Effect. / Trans. Shunted.	$1+\frac{n}{s}$ Calculated.
28·2	– 0·37519	– 0·18141	2·068	2·062
66·7	– 0·57451	– 0·25566	2·247	2·25
147·0	– 0·70719	– 0·25157	2·8111	2·826

PLATE III.

This plate was of pure bismuth, specially prepared by Professor Classen in Aachen.

Length, ... 1·99 cm.
Breadth, ... 1·075 „
Thickness, ... 0·126975 „

Field Strength.	Trans. Effect.	Trans. Effect with Shunt.	Trans. Effect. / Trans. Shunted.	$1+\frac{n}{s}$ Calculated.
9·4	– 0·05219	– 0·03953	1·320	1·327
55·0	– 0·16162	– 0·113	1·430	1·415
100·0	– 0·22199	– 0·14378	1·543	1·539
138·2	– 0·27166	– 0·16375	1·658	1·660
146·0	– 0·2812	– 0·16676	1·6777	1·679
153·0	– 0·28849	– 0·17034	1·6936	1·6929

PLATE VI.

Rapidly cooled; made from first supply of bismuth.

Length,	5·81	cm.
Breadth,	2·9935	„
Thickness,	0·14105	„

Field.	Trans. Current.	Trans. Current Shunted.	$\frac{\text{Trans. Current.}}{\text{Trans. Current Shunted.}}$	$1+\frac{n}{s}$ Calculated.
48·4	−0·0185	−0·0075	2·4666	2·4671
87·2	+0·05646	+0·02206	2·5628	2·5621
118·0	+0·11916	+0·0461	2·5845	2·558

PLATE VII.

Slowly cooled; made from first supply of bismuth.

Length,	6·032
Breadth,	1·507
Thickness,	0·06713

Field.	Trans. Current.	Trans. Current Shunted.	$\frac{\text{Trans. Current.}}{\text{Trans. Current Shunted.}}$	$1+\frac{n}{s}$ Calculated.
17·8	−0·2536	−0·00883	2·872	2·8979
121·6	+0·1852	+0·06045	3·0637	3·0667
140·0	+0·22024	+0·07243	3·0407	3·0805
147·8	+0·2484	+0·08184	3·0352	3·0543

PLATE VIII.

Quickly cooled; made from new supply of bismuth.

Length,	5·99	cm.
Breadth,	3·03	„
Thickness,	0·3153	„

Field.	Trans. Current.	Trans. Current Shunted.	$\frac{\text{Trans. Current.}}{\text{Trans. Current Shunted.}}$	$1+\frac{n}{s}$ Calculated.
41·4	−0·09817	−0·0651	1·5077	1·5016
80·2	−0·108	−0·06846	1·5775	1·5799
100·0	−0·09986	−0·06144	1·6253	1·6251
123·3	−0·09026	−0·05554	1·6251	1·6475

It will be seen from a comparison of the last two columns in the different results that

the agreement between the observed and the calculated values of $1+\frac{n}{s}$ is in most cases close; the discrepancies can be quite well accounted for by experimental errors in measuring such small resistances.

Section III.—On the Change of Sign of the Transverse Effect.

In Plate I. it was noticed that the transverse effect attained a maximum and then decreased steadily with increasing fields. Other plates were then made, to see if this result was observable in them; and in some of them the maximum was reached with comparatively weak fields. With stronger fields the transverse current decreased, till finally it vanished; with still stronger fields it reappeared again, but with the opposite direction.

With Plate VI., as originally prepared, the following results were obtained :—

Field.	Transverse Effect.	Sign.	Rotatory Coefficient.
3·5	·01179	−	3·83
5·0	·01648	−	3·74
11·5	·0302	−	2·99
19·0	·03595	−	2·15
22·0	·03993	−	2·06
32·0	·03787	−	1·35
40·0	·03183	−	0·88
48·4	·0185	−	0·43
53·0	·01625	−	0·35
60·0	·0032	−	0·06
65·0	·0057	+	0·1
77·6	·03432	+	0·5
87·2	·05646	+	0·74
118·0	·11916	+	1·15
127·2	·14305	+	1·28

Here the transverse effect is at first negative; it increases, till with a field strength between $22 \times 138{\cdot}5$ and $32 \times 138{\cdot}5$ in c.g.s. units, it reaches a maximum. After that it decreases and finally vanishes between 60 and 65. It begins again, however, with increasing fields, and continues to increase; but now it has the opposite sign. The rotatory coefficient has its greatest—and negative—value with the weakest field.

This same plate was next shortened and narrowed, but the thickness kept as before. The transverse effect was again observed; it was still the same in character. It vanished with the same field strength as in the previous experiment; and with weak fields was negative, with strong positive.

Next the plate was made thinner by planing, and the following results were obtained :—

Plate VI.

Length,	4·22	cm.
Breadth,	2·36	„
Thickness,	0·0657	„

Field.	Transverse Effect.	Sign.	Rotatory Coefficient.
23·4	0·08714	−	1·97
29·0	0·09326	−	1·70
35·2	0·08958	−	1·35
41·8	0·08033	−	1·02
45·0	0·06857	−	0·081
69·0	Not observed.		
80·0	0·03144	+	0·21
102·8	0·12287	+	0·63
110·0	0·20363	+	0·88

A comparison of these results with those obtained with the original plate shows that the maximum negative effect is reached with a higher field, and that the field strength for which the effect vanishes is also higher. If we take the magnetic force as abscissa, the transverse effect as ordinate, we may express the result by stating that the curve giving the relation between the two has been moved, so that it cuts the axis at a point farther along in the positive direction.

See graph of curve giving relation between transverse effect and field strength in fig. 3, where A is the curve for the plate as originally cast, B that after it was hammered, C that after it was planed down.

Finally, the dimensions of the plate were again slightly modified, and, in addition, it was hammered.

PLATE VI.

Length,	3·25	cm.
Breadth,	1·24	„
Thickness,	0·0657	„

Field.	Transverse Effect.	Sign.	Rotatory Coefficient.
49·0	0·1075	−	1·16
66·1	0·08014	−	0·64
76·0	0·0394	−	0·27
85·0	Not observed.		
123·1	0·12246	+	0·527
134·0	0·1657	+	0·66

In this instance the reversal of sign takes place with a still stronger field. An attempt to further thin the plate proved abortive; it was now so brittle that planing caused it to break.

In Plate VII. the reversal was also observed in the plate as originally made; the effect disappeared with a field strength of $43 \times 138{\cdot}5$ c.g.s. It was then halved and the transverse effect for both halves was observed, and was found to vanish for the same field strength. Finally, one half was hammered; the same results—negative for the weaker fields, positive for the higher—were obtained, but the vanishing did not now take place until a field strength $60 \times 138{\cdot}5$ was reached.

Plate Ib also showed this reversal. For the original plate the following results were obtained :—

PLATE Ib.

Length,	6·045	cm.
Breadth,	2·58	,,
Thickness,	0·12235	,,

Field.	Transverse Effect.	Sign.	Rotatory Coefficient.
8·0	0·0302	−	3·72
15·1	0·05276	−	3·45
28·0	0·05517	−	1·94
38·0	0·0484	−	1·26
59·0	0·0218	−	0·36
63·0	0·003	−	0·046
75·6	0·02229	−	0·29
118·0	0·14253	+	1·19
140·0	0·20239	+	1·43
148·0	0·22356	+	1·49

The transverse effect is first negative ; it increases and reaches its maximum negative effect with field strength 28 (about). Afterwards it decreases and vanishes with field 63 (about). It again appears and increases for all other fields higher than 63, but now has the opposite direction.

This plate was next varied in length and in breadth, but the same thickness was retained ; and the transverse effect was found to vanish for the same field strength.

The plate was then hammered, and it was found that the transverse effect did not vanish until a field strength of about 80 was reached ; the field strength by which the maximum negative effect was reached was also greater.

The plate was now made thinner by planing—

Length,	4·47	cm.
Breadth,	2·08	,,
Thickness,	0·0665	,,

Field Strength.	Transverse Effect.	Sign.	Rotatory Coefficient.
26·0	0·21699	−	4·48
38·0	0·22231	−	3·14
49·0	0·21172	−	2·32
62·0	0·13521	−	1·17
87·0	0·4749	−	0·29
97·0	Not Observed.		
101·0	0·0376	+	0·199
117·8	0·17013	+	0·77
135·0	0·27122	+	1·08
145·0	0·33084	+	1·22

We see that a still stronger field is now required to make the transverse effect vanish; and for the maximum negative effect also a stronger field is necessary than in the former cases.

Finally, the plate was again hammered, and the following results obtained :—

Field Strength.	Transverse Effect.	Sign.	Rotatory Coefficient.
50·0	0·23289	−	2·5
70·0	0·16731	−	1·28
100·0	0·01837	−	0·098
105·6	0·02256	+	0·115
123·5	0·11556	+	0·502
143·0	0·21119	+	0·79

which again shows a considerable increase in the field necessary to reverse the direction of the transverse current.

The reversal of direction was not observed in Plates II. and III., nor was a maximum effect reached in these two plates: In Plate I., again, no reversal was found, but a maximum effect was reached with a field strength a little over 100.

Another series of plates was now made from a new supply of mercantile bismuth. Two Plates, VIII. and IX., were made each about 3 mm. thick; VIII. was cooled quickly, IX. slowly. The transverse effect was negative throughout; it reached a maximum in both cases, and then began to decrease; but it could not be made to vanish by field strengths at disposal.

Two other Plates, X. and XI., were made, each about 1·5 mm. thick; X. was cooled quickly, XI. slowly. In these two plates the transverse current vanished, and with higher fields had the opposite sign positive.

Another Plate, XII., was made in the form of a cross; to the two arms of the cross the galvanometer wires were soldered, and the effect of the soldering on the plate as a whole minimised. (Cp. fig. E.) With this plate the following results were obtained:—

PLATE XII.

Length, ...	6·22
Breadth, ...	1·85
Thickness, ...	0·10462

Field Strength.	Transverse Effect.	Sign.	Rotatory Coefficient.
25·2	0·17158	−	5·74
34·6	0·18389	−	4·48
45·5	0·18115	−	3·36
88·3	0·05617	−	0·538
103·0	0·0119	+	0·097
116·5	0·06051	+	0·438
137·0	0·16766	+	1·033
145·0	0·20602	+	1·199

We may sum up the results as follows:—With thick plates the transverse current does not change its direction for any strength of field, though in some cases a maximum value is reached and passed; nor can the change of direction be brought about by planing, hammering, or modifying the dimensions of the plates. Cp. fig. 1, which gives the relation between field and effect for Plate IA, and fig. 2, which gives the same for Plate II.

With thinner plates the transverse current is positive for strong fields, negative for weak ones. The field strength at which vanishing takes place is the same for the same plate, so long as it is modified only in length and breadth; but if the plate be planed down, the field at which the current vanishes is stronger than in the original case. Similarly, if the original plate be hammered, the field required to produce vanishing is stronger: a combination of hammering and planing raises very considerably the strength of the field required. From a comparison of the results, it will be seen that in different plates the transverse current vanishes for different fields. Cp. fig. 3, where the three curves give the relation between field strength and transverse effect for Plate IB; A refers to the original plate, B to the same plate hammered, C to it after planing.

This reversal of the transverse current has already been observed by VON ETTINGSHAUSEN and NERNST* in an amalgam of bismuth and tin.

In the one certainly pure bismuth, Plate III., the ratio of the increase of resistance to the square of the transverse effect, was practically constant; this is as it should be, if in diamagnetic bodies the transverse effect is, as in the magnetic metals, proportional to the magnetisation I, and the increase of resistance proportional to, I^2. If we start from this and apply it to those plates in which the transverse effect vanishes, we find that our facts do not tally with our assumptions. For if the transverse current be proportional to the magnetisation, when the former vanishes, so must the latter and so must the increase of resistance too: that is, when the transverse current vanishes, the resistance of the bismuth at the same field strength must be the same as when no field is present. But for Plate IB. the following results were obtained:—

Field Strength.	Resistance Proportional to.	Transverse Effect.
0·0	254·0	0
28·0	265·4	−0·5517
63·0	280·1	−0·003
118·0	300·2	+0·14253
147·7	312·0	+0·22356

That is, the transverse effect vanishes at about 63, but the resistance increase is at the same field strength quite perceptible. Another effect observed in all the plates and which will be later described, supports the view that the increase of resistance does not vanish with

* *Sitz. bericht der kais. Akad. der Wissenschaft*, ii. Abth., 1887, Bd. 96.

the transverse effect. From this we may draw three conclusions:—(1) The two assumptions are both wrong; (2) one is wrong; (3) or we may still suppose both true, and assume that in bismuth two constants with opposite signs are involved in the transverse effect. That is, instead of assuming that it is proportional to the vector product of the primary current and the magnetisation, we assume that it is the vector product of the primary current and $(c_1 I + c_2 I^3)$.

In the first case we may write the electromotive force

$$e = c_1 \nabla u I$$

where c_1 is negative for bismuth and those metals which have a negative transverse effect; positive for those which have a positive effect.

In the second case

$$e = \nabla u (c_1 I + c_2 I^3)$$

where c_1 is the same constant as before, c_2 is another constant positive in the first class of substances negative in the second. In those substances in which the transverse effect is proportional to the magnetisation, c_2 is infinitesimally small in comparison with c_1; in bismuth and any other substances where this is not the case, c_2 has such a value that for sufficiently high fields the transverse effect may vanish, and for still higher reverse its direction. Similarly, c_2 might be of such magnitude that the transverse effect did not vanish, but still reached a maximum value, and then began to decrease as in Plate IA, fig. 1.

The validity of this assumption could be tested by determining the magnetisation directly, and thus determining c_1 and c_2 for different field strengths.

Section IV.—On Effects other than the Transverse Effect proper.

Two other such effects were observed. The first was evident in the whole of the plates experimented upon. In the plate of pure bismuth, III., it was such, that when the apparatus was arranged, as in diagram (D), in passing from the entrance of the primary current at B to that of the effect at D, the motion was counter-clockwise. It changed with the change in direction of the primary current, but not with the reversal of the magnet. Thus, with one arrangement of the magnet, it acted against the transverse current; in the other with it. In Plate III. it acted against the transverse current when the north pole of the magnet was in front of the diagram, with it when the south pole was in front.

The following results were obtained with Plate III. :—

Field, . .	55·0	100·0	138·2	153·0
Effect, . .	0·03613	0·08908	0·14475	0·16332

To find how this effect varied with the primary current strength, the field was kept constant, while the primary was varied :—

Primary Current Proportional to.	Effect in Scale Parts.	$\frac{\text{Effect.}}{\text{Primary.}}$
60·0	90·0	1·5
124·1	177·6	1·43
187·0	269·4	1·44
373·0	515·4	1·39

or the effect is, for the currents used, practically directly proportional to the primary current.

This effect had the same direction in Plate II., for which the following results were obtained :—

Field, . . .	36·0	61·0	120·0	137·0	146·0
Effect, . . .	0	0·0045	0·0509	0·07175	0·084

In Plate XII. again the direction of the effect was the opposite. In the other plates it had sometimes the one direction, sometimes the other ; indeed, after a plate had been planed or hammered, it sometimes had the opposite direction to that in the original plate. So long as it was less in magnitude than the transverse effect proper, its disturbing influence was eliminated by making four different experiments, according as the direction of the field or the primary current was varied. Should it, however, have a greater value than the transverse current, this was no longer the case ; and when the transverse current vanished, it alone was observable ; it increased in all cases with the field strength, and in no case did it change sign, unless the plate was modified.

The existence of an effect whose direction can in no case be predicted follows from the general equations for a non-isotropic body. For, suppose we have an isotropic body which is brought into a magnetic field and carries a current, it is acted on by mechanical forces. The body becomes anisotropic, and the transverse coefficients of resistance are brought into play ; a transverse current flows, whose direction is determined by the structure of the body. Or, suppose the body to be originally non-isotropic, a transverse current will be observed with no magnetic field present ; this, however, can be eliminated by the insertion of a proper resistance. When the magnet is excited, the transverse resistance is modified, so that the inserted resistance no longer balances it. Result is, the transverse current again appears. The fact that it does not depend on the direction of the field shows that the resistance concerned is proportional to some even function of the magnetisation.

The equations for such a body would be

$$X = r_{11}u + r_{12}v + r_{13}w$$
$$Y = r_{12}u + r_{22}v + r_{23}w$$
$$Z = r_{13}u + r_{23}v + r_{33}w$$

If to this we add the fact that a magnetic field gives rise to a rotatory coefficient as well, which is an odd function of the magnetisation, we have the most general equations

$$X = r_{11}u + r_{12}v + r_{13}w + T_3v - T_2w$$
$$Y = r_{12}u + r_{22}v + r_{23}w + T_1w - T_3u$$
$$Z = r_{13}u + r_{23}v + r_{33}w + T_2u - T_1v$$

where x, y, z are the components of the electromotive force parallel the three axes; u, v, w the components of the current; p_{11}, r_{22}, r_{33} the direct resistances; r_{12}, r_{13}, r_{23} the transverse resistances; T_1, T_2, T_3 the rotatory resistances.

The second effect was not observed in all the plates. Its presence was observed by the gradual decline of the galvanometer deflexion of the transverse current, which lasted for about a minute, when a steady state was usually reached. It was measured in the following manner:—After the steady transverse reading had been taken, the electromagnet was kept on, the primary current was broken, and the galvanometer immediately inserted. The reading thus obtained was usually small and died away gradually. In every instance it was oppositely directed to the transverse current.

PLATE I.

Length, ... 5·45 cm.
Breadth, ... 2·96 „
Thickness, ... 0·1305 „

Field, . .	9·6	36·8	58·0	119·0	131·5	141
Effect, . .	0·0069	0·0319	0·0437	0·0429	0·0381	0·0371

The numbers given under "effect" are here, as before the galvanometer reading, divided by the primary current.

The same plate was previously used, its thickness then being 0·19416 cm.

Field, . . .	24·0	52·2	98·0	114·2	131·0
Effect, . . .	0·0213	0·0288	0·0334	0·0343	0·03133

PLATE II.

Length, ... 6·26 cm.
Breadth, ... 2·945 „
Thickness, ... 0·1497 „

Field, . . .	36·0	61·0	120·0	137·0	146·0
Effect, . . .	0·01746	0·0343	0·0718	0·0806	0·084

The same plate planed to thickness, 0·08277 cm.

Field, . .	15·7	28·2	66·7	94·2	110·0	147·0
Effect, . .	0·0068	0·02114	0·0608	0·0878	0·1045	0·122

PLATE III.

Length, ... 1·99 cm.
Breadth, ... 1·075 „
Thickness, ... 0·12697 „

Field, . .	98·0	138·0	146·0	153·0
Effect, . .	0·0362	0·06246	0·06349	0·06904

The same plate was planed to thickness, 0·09 cm.

Field, . . .	33·8	61·0	93·2	110·0	153·0
Effect, . . .	0·0125	0·03061	0·04977	0·0609	0·06831

It will be observed that in Plate I. a maximum effect is reached just as was the case with the transverse effect in that plate; and in II. and III. no such maximum effect was reached again agreeing with the transverse current.

The same effect was observed and measured in Plates VIII. and IX.; in those plates which gave a reversal of the transverse current; the result was too small to be measured accurately. In some cases, however, it was noticeable and always directed against the transverse current. In those plates in which the effect was observed, it must be added to the transverse effect to give the latter its proper value.

To find how this effect depended on the current, the field was kept constant, and four different currents used.

Primary Current in Scale Parts.	$\frac{\text{Effect in Scale Parts.}}{\text{Primary in Scale Parts.}}$
60·0	0·06458
124·1	0·06305
187·1	0·062
373·0	0·06246

or for the currents used, the effect is proportional to the current.

To explain this effect we must remember that the body carrying the current in a magnetic field is subject to mechanical force and is also heated by the current. According to Joule's law the heating is proportional to the square of the current strength; it

cannot, therefore, be due to this heating effect, otherwise its direction would be independent of that of the primary current. We must rather suppose that it is the result of a kind of Peltier effect, arising from the heating of a substance differently deformed in different parts. Should this be so, it might be possible to map out a plate into pressed and stretched regions by observing the direction of the effect in different parts of the plate.

For let us assume, after BIDWELL,* that the plate is deforming in the following manner so that A B represents a compressed part, B F a stretched, and so on ; then if the electrodes are at L and M, the current is in the direction L M ; should they be at N and O the current would be in the direction N O,—that is opposite to the former (fig. F).

If such be the explanation, we should expect to find an electromotive force created in a heated body when it is placed in a magnetic field ; this has been observed by ETTINGSHAUSEN and NERNST.†

* *Phil. Mag.*, 1884.

† WIEDEMANN'S *Annalen*, 1887, Bd. 31.

Mr. J. C. Beattie on the Transverse Effect in Bismuth.

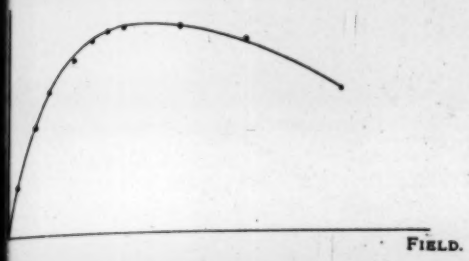
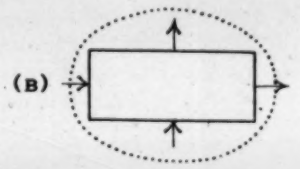


Fig. 1.



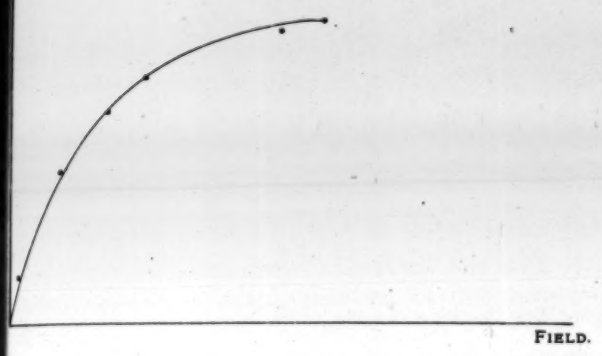
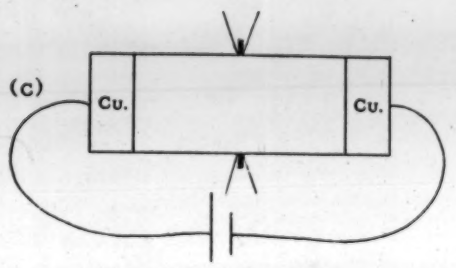


Fig. 2.



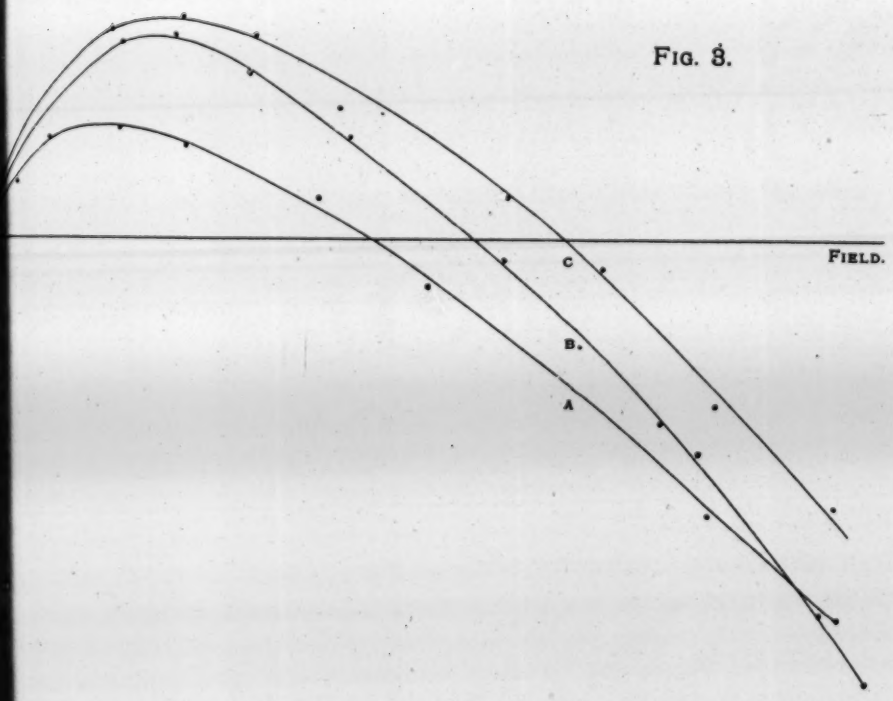
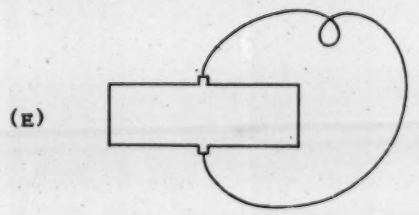
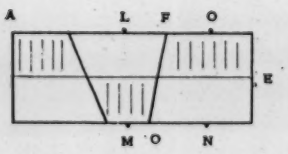
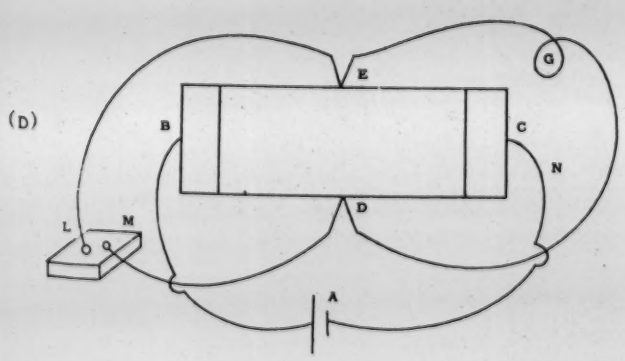
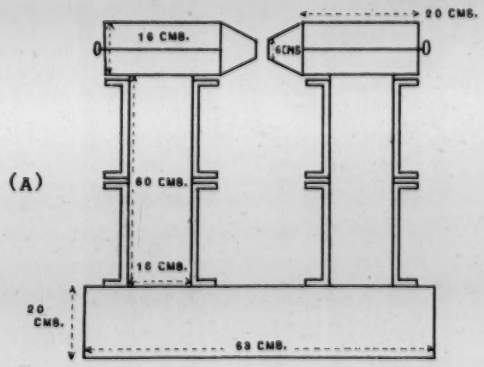


Fig. 3.









VII.—*On the Relation between the Variation of Resistance in Bismuth in a Steady Magnetic Field and the Rotatory or Transverse Effect.* By J. C. Beattie. (With a Plate.)

(Read 17th June 1895.)

Kundt* has shown that the transverse effect in iron, cobalt, and nickel is proportional to the magnetisation. Such an effect, where the magnetisation appears in the first power, we shall call a Hall effect. In applying the same method to bismuth, he found that no transverse effect was given by the thin plates of the electrolitically deposited metal used by him. That this absence of transverse effect is not characteristic of all bismuth so prepared has been shown experimentally. The question is, What relation, if any, exists between it and the magnetisation? To settle this it is necessary to compare the transverse effect in any given plate with some other effect in the same plate whose relation to the magnetisation is known. Such an effect is the variation of resistance. Goldhammer† has shown that this latter is proportional to the square of the magnetisation.

The current sent through the plate is called the primary. A thick copper wire was placed in the primary circuit, so that two fixed points in it could be inserted in the galvanometer circuit; the reading thus obtained was used as a measure of the strength of the current. This brings in no error, since the measurements are throughout relative.

By the rotatory or transverse effect is meant the ratio of half the galvanometer deflection (with proper sign), which is obtained when two equipotential or approximately equipotential points on opposite sides of the plate are inserted in the galvanometer circuit, to the strength of the primary current. The numerical value of this effect is denoted by E.

To measure the resistance of the plate, two fixed points or lines in it were inserted in the galvanometer circuit; the reading thus obtained divided by the strength of the primary current was taken to be proportional to the actual resistance of the plate. By this means it is rendered independent of the current strength.

The resistance $n + \Delta n$ of a plate in a steady magnetic field, minus its resistance (n), when no field was there,—that is, Δn can be taken as proportional to the square of the magnetisation.

If the transverse effect is a pure Hall, we shall have

$$c_1 \sqrt{\Delta n} = \pm E \quad . \quad . \quad . \quad (1)$$

Evidently this cannot hold for plates where E attains a maximum value: in such we must use a formula

$$c_1(\Delta n)^{\frac{1}{2}} + c_2(\Delta n)^{\frac{3}{2}} = \pm E \quad . \quad (2)$$

In the following experiments a d'Arsonval galvanometer was used. The electromagnet was ring-formed, and was wound with a wire capable of carrying a thirty ampere

* Wiedemann's *Annalen Neue Folge*, Bd. 49, 1893. † *Ibid.*, Bd. 36, 1889.

current; the poles were circular surfaces 60 mm. in diameter and 18 mm. apart. By inserting suitable resistances in the electro-magnet circuit any field required could be obtained.

The field strength was measured by Verdet's method: as the strength does not come directly into the calculations it is given only approximately. The necessary measurements were made some weeks after the other experiments.

The plates used were fixed on to strips of ebonite; at both ends copper of the same breadth and thickness was soldered on, the ends of the copper dipped into pools of mercury. The two pools could be connected with the primary current and with the galvanometer simultaneously; in this way the resistance of the plate perpendicular to the direction of the field was measured. It is to be noted that the resistance of the copper plates comes in, but as this does not vary in a magnetic field, Δn is not affected.

To measure the transverse effect and the resistance along the lines of force two wires arranged as in fig. 1, were soldered on to the two middle points of the sides of the bismuth plate; the ends of these wires dipped into four small mercury pools.

The plates so arranged could be clamped in the field in either of two positions at right angles to one another.

Three different positions of the plate with respect to the lines of force of the field were considered.

Suppose the direction of the field to be parallel to the plane of the paper, and let this be our y-axis: let the z-axis be drawn perpendicularly upwards, the x-axis towards the reader. In the first position (α) the plate's surface was in the xz plane, and the primary current flowed in the z direction. In the second position (β) the plate's surface was in the yz plane, and the primary current flowed in the direction z. The resistance measured in both these cases is the resistance perpendicular to the lines of force of the magnetic field.

In the third position (γ) the plate's surface was in the yz plane, and the primary current flowed in the direction y. With this arrangement the resistance along the lines of force could be measured by sending the primary current in at (1) or (2), while at the same time (3) and (4) were joined to the galvanometer.

It was found, however, that this latter arrangement was not very suitable, and in the greater number of cases another method (fig. δ) was used. The plate was fixed on to another piece of ebonite. Along the sides thick copper wires were soldered throughout the whole length; these served for the primary current. Two other wires were soldered along the length of the plate, but were not in direct contact with the other two: one end of each of these was joined to the galvanometer.

The transverse effect was measured with the plate in position α.

No attempt was made to keep the temperature of the plate constant by using liquids; the temperatures given are the approximate temperatures of the room during the time of the experiment. Between the different experiments, however, a pause was made to allow the plate to cool.

It may be stated that for weak fields the method here given for measuring the resistance is not suitable. For such the Wheatstone bridge or the differential galvanometer would give good results in less time.

Of the different plates used, only one was known to be perfectly pure. With it the following results were obtained :—

Length, . . . 16·75
Breadth, . . . 7·2 } mm. Temp. 10° C. $n = ·9521$
Thickness, . . ·9

$$c_1 = \frac{-E}{\sqrt{\Delta n}}$$

Field in cgs. Units.	Transverse Effect.	α		β		γ		α	β	γ
		Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$			
8,500	−·2311	·2949	·5420	·3144	·5648	·1489	·3858	−·42	−·41	−·60
9,500	−·2455	·3292	·5738	·3556	·5963	·1622	·4027	−·42	−·41	−·60
11,700	−·2627	·4001	·6325	·4333	·6582	·1780	·4219	−·41	−·40	−·62
12,840	−·2708	·4552	·6747	·4717	·6768	·2066	·4545	−·40	−·40	−·59
14,170	−·2974	·4815	·6932	·5258	·7251	·2357	·4855	−·42	−·40	−·61
15,600	−·3071	·5881	·7669	·5684	·7539	·2500	·5000	−·40	−·40	−·61
17,800	−·3271	·6281	·7926	·6252	·7907	·2704	·5389	−·41	−·41	−·60

The relation between the transverse effect and the variation of resistance is a simple one. The constants obtained for the positions α and β are the same : that for γ is different ; but it is to be remembered that the results given above depend upon the form of the plate and upon the external resistance inserted in the galvanometer circuit, which differed in position γ from that in α and β. To eliminate the various disturbing effects the quantity $\sqrt{\frac{\Delta n}{n}}$ should be used in equation (1) instead of $\sqrt{\Delta n}$.

The two next plates were made from different supplies of commercial bismuth. In them the numerical value of the transverse effect did not reach a maximum with the fields at disposal.

In Plate II. the simple relation (1) no longer applies ; the equation (2) was therefore used.

The average values of the constants c_1 and c_2 were obtained by solving the equations obtained from combining the results for each field with those for every other ; the two results immediately before and after were in each case rejected :—that is, with twelve different field strengths, 1 . . . 12, we get eleven equations by combining result 6 say with all others, but of these those derived from 5 and 7 were rejected.

PLATE II.

Length, . . . 16·5
Breadth, . . . 8·0 } mm.
Thickness, . . . ·827

$n = ·83$
Temp. 9° C.

$c_1(\Delta n)^{\frac{1}{2}} + c_2(\Delta n)^{\frac{3}{2}} = -E.$

Field in cgs. Units.	Trans. Effect.	α		β		γ		α		β		γ	
		Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$	c_1	c_2	c_1	c_2	c_1	c_2
1,170	−·1087	·0110	·1049	...		...		...		...		...	
1,840	−·1270	·0150	·1279	...		...		...		...		...	
2,520	−·2220	·0460	·2145	...		...		−1·04	+·30	...		...	
3,180	−·3249	·1041	·3229	·1018	·3190	...		−1·04	+·30	−1·05	+·32	...	
5,030	−·3840	·1499	·3872	...		·2865	·5352	−1·04	+·30	...		...	
8,500	−·5147	·2945	·5427	...		·5696	·7540	−1·04	+·31	...		−·74	+1·2
9,500	−·5264	·3130	·5594	...		...		−1·04	+·30	...		...	
11,740	−·5679	·3756	·6129	·3805	·6163	·7577	·8704	−1·04	+·30	−1·04	+·30	−·74	+1·1
12,840	−·6075	·4573	·6761	...		...		−1·04	+·30	...		...	
14,200	−·6181	·4919	·7013	·4820	·6944	...		−1·04	+·30	−1·04	+·28	...	
15,600	−·6302	·5300	·7215	...		...		−1·04	+·30	...		...	
17,780	−·6600	·6081	·7798	·6023	·7716	1·0062	1·0031	−1·04	+·30	...		−·75	+1·2
						Average,		−1·04	+·31	−1·04	+·31	−·75	+1·2

In Plate IX. the relation between the transverse effect and the resistance variation perpendicular to the field was alone considered. Owing to the size of the plate the arrangement —ϵ— was somewhat different. The plate was fixed on to stiff cardboard, the transverse electrodes were soldered to the middle points of the sides, the primary electrodes to the middle points of the ends. The plate was then placed with its surface perpendicular to the lines of magnetic induction and kept clamped in this position.

We see that in these two plates we have not to deal with a pure Hall effect only; we have in addition a second effect, which is positive and proportional to $(\Delta n)^{\frac{3}{2}}$ that is to the magnetisation cubed.

The results for Plate IX. and for all the plates showing two effects can be represented graphically; the resistance variation is measured along the horizontal axis. Along the perpendicular axis the values of $\frac{-E}{\sqrt{\Delta n}}$ are laid down; the connecting curve is a straight line, which, when produced to meet the perpendicular axis, gives the value of c_1. To obtain such a curve for any plate, at least two direct measurements of the

PLATE IX.

Length, . . . 60·1
Breadth, . . . 30·3 } mm.
Thickness, . . . 3·1785

$n = 1{\cdot}4052$
Temp. 14° C.

Field.	Trans. Effect.	δ Δn	$\sqrt{\Delta n}$	$\frac{c_1}{c_1}(\Delta n)^{\frac{1}{2}} + \frac{c_2}{c_2}(\Delta n)^{\frac{3}{2}} = \text{E.}$	
1,340	– ·0469	·0240	·1549	...	...
3,350	– ·0943	·1020	·3194	– ·30	+ ·097
5,030	– ·1202	·1760	·4195	– ·30	+ ·107
6,700	– ·1505	·2975	·5454	– ·30	+ ·098
8,800	– ·1700	·4190	·6473	– ·30	+ ·101
11,300	– ·1879	·5823	·7631	– ·30	+ ·101
14,750	– ·1999	·7735	·8795	– ·30	+ ·100
17,780	– ·2072	·9870	·9985	– ·30	+ ·098
			Average	– ·30	+ ·100

transverse effect and of the variation of resistance must be made; with these we obtain two points on our line. For any other variation of resistance value we can then find the transverse effect and resolve it into a pure Hall effect and this second effect.

Evidently the graphic method could also be applied to determine c_1 and c_2 in the first instance, instead of the method of equations used in this paper.

The next plates used were two in which the transverse effect attains a maximum numerical value.

In these two plates also, which were made from the same two supplies of bismuth, we have two effects.

Finally, two plates were considered in which the second effect is so great as to completely mask the true Hall, so that even with the low fields at disposal the transverse effect changes sign.

The results of experiments with Plates IB. and VI. by a different method:—viz., that described in paper, "On Hall Effect and some Related Effects in Bismuth," were qualitatively the same. For IB. the values of c_1 and c_2 were respectively $c_1 = -{\cdot}45$ $c_2 = +4{\cdot}4$ and for VI. $c_1 = -{\cdot}238$ $c_2 = +3{\cdot}3$.

We may sum up the results so far obtained by saying that in the pure bismuth plate the Hall effect alone is present: it is proportional to $(\Delta n)^{\frac{1}{2}}$ and is negative in sign. In the other plates the transverse effect is composed of two effects, the pure Hall and another, positive in sign and proportional to $(\Delta n)^{\frac{3}{2}}$. In different plates this effect

appears in different magnitude; in some it is relatively so small, compared to the Hall effect, that it does not, with the fields at disposal, cause the total effect to decrease numerically. In others, again, it produces this; and in a third class it

PLATE VIII.

Length, . . . 24·0
Breadth, . . . 12·0 } mm.
Thickness, . . . 1·1365

$n = 1{\cdot}3967$
Temp. 15° C.

$c_1(\Delta n)^{\frac{1}{2}} + c_2(\Delta n)^{\frac{3}{2}} = -E.$

Field.	Trans. Effect.	α		β		γ		δ	
		Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$	c_1	c_2	c_1	c_2
1,340	−·10221	·0320	·1780	...	...	...	...	...	...
3,350	−·19552	·1253	·3539	·0452	·2126	...	...	...	...
5,030	·23712	·2029	·4500	·0712	·2668	−·58	+·27	−·96	1·2
6,700	−·28526	·3244	·5697	·1135	·3369	−·58	+·25	−·96	1·1
11,300	−·33459	·6067	·7789	·1943	·4409	−·58	+·25	−·96	1·1
12,840	−·33879	·7199	·8489	...	...	−·58	+·25	...	..
14,750	−·33456	·7803	·8833	·2416	·4914	−·58	+·26	−·96	1·2
17,780	−·3147	·9709	·9853	·2699	·5195	−·57	+·26	−·98	1·4
					Average	−·58	+·26	−·97	1·2

PLATE Ia.—ARRANGEMENT ϵ.

Length, . . . 50
Breadth, . . . 28·25 } mm.
Thickness, . . . 1·305

$n = 1{\cdot}056$
Temp. 15° C.

$c_1(\Delta n)^{\frac{1}{2}} + c_2(\Delta n)^{\frac{3}{2}} = -E.$

Field.	Trans. Effect.	Δn	$\sqrt{\Delta n}$	c_1	c_2
8,500	−·2902	·2529	·5029	...	...
11,740	−·2900	·3262	·5712	−·83	+·98
12,840	−·2898	·3274	·5722	−·81	+·94
14,170	−·2739	·4121	·6419	−·83	+·95
15,600	−·2621	·4321	·6573	−·80	+·99
17,780	−·2503	·4816	·6939	−·82	+·95
			Average	−·82	+·96

PLATE XII.

Length, . . . 24·0
Breadth, . . . 11·75 } mm.
Thickness, . . . ·95

$n = 2{\cdot}08$
Temp. 14° C.

$c_1(\Delta n)^{\frac{1}{2}} + c_2(\Delta n)^{\frac{3}{2}} = \pm E.$

Field.	Trans. Effect.	α		β		α		β	
		Δn	$\sqrt{\Delta n}$	Δn	$\sqrt{\Delta n}$	c_1	c_2	c_1	c_2
1,340	− ·0475	·0139	·1179		...		...		...
2,680	− ·07266	·0373	·1931		...		...		...
3,350	− ·08131	·0517	·2274	·0382	·1955	− ·41	+ 1·2		...
5,030	− ·0976	·0776	·2786	·0559	·2383	− ·41	1·2	− ·50	+ 2·2
6,700	− ·08922	·1393	·3732	·0900	·3000	− ·42	1·3	− ·50	+ 2·3
8,820	− ·07009	·1906	·4366	·1282	·3580	− ·41	1·3	− ·50	2·4
14,750	− ·00519	·3318	·5760		...	− ·43	1·2		...
17,780	+ ·04702	·3816	·6177	·2322	·4819	− ·42	1·3	− ·50	2·4
					Average,	− ·42	+ 1·3	− ·50	+ 2·5

PLATE X.

Length, . . . 38·8
Breadth, . . . 20·5 } mm.
Thickness, . . . 1·112

1·8041
Temp. 9° C.

$c_1 \sqrt{\Delta n} + c_2(\Delta n)^{\frac{3}{2}} = \pm E.$

Field.	Trans. Effect.	ϵ		c_1	c_2
		Δn	$\sqrt{\Delta n}$		
1,840	·01708	·0148	·1217	...	
2,520	− ·01944	·0221	·1487	...	
3,180	− ·01974	·0400	·2000	− ·16	+ 1·7
4,100	− ·01784	·0455	·2133	− ·16	1·8
8,500	+ ·01361	·1300	·3606	− ·17	1·6
10,800	+ ·02650	·1502	·5875	− ·15	1·6
12,840	+ ·06014	·1830	·4278	− ·15	1·7
14,170	+ ·07676	·1977	·4448	− ·16	1·7
15,600	+ ·09602	·2033	·4575	− ·16	1·8
17,780	+ ·12024	·2215	·4707	− ·16	1·8

is present to such an extent that in the end it gives its sign to the total transverse effect.

This second effect is not to be confounded with the thermo-magnetic effect observed by ETTINGSHAUSEN and NERNST: the latter is evidently proportional to $(\Delta n)^{\frac{1}{2}}$ and positive in sign.

The anomalous behaviour of the transverse effect in bismuth—which is hidden, if the effect be represented in terms of the rotatory co-efficient R—has also been observed by ETTINGSHAUSEN and NERNST.* They found that in a specimen of pure bismuth, E obtained a maximum value,—that is, both effects may appear in pure bismuth. Again, ETTINGSHAUSEN† has shown that, in an alloy of tin and bismuth, the transverse effect changes sign. At high fields, when little tin is present: at lower, when more tin is added until when the alloy contains 6 % tin, 94 % bismuth, the positive sign alone is present. The explanation lies in the presence of this second effect, which increases relatively to the pure Hall effect as the proportion of tin to bismuth increases.

It is interesting to note that the relation between transverse effect and resistance variation holds, no matter what the percentage increase of resistance is, or how much the transverse effects expressed in terms of R vary in the different plates.

So far, the transverse effect has only been observed when the electrodes are at the middle points of the sides. A number of experiments were next made with these electrodes at different parts, while still kept opposite each other. In Plate IA. the numerical value of the transverse effect was found to have a maximum value with the electrodes in the middle; for other positions it was less. The greater the distance from the middle points, the greater was the decrease. Next, the same plate was cut along the middle line for about half its length. The electrodes were fixed at *a b*, *c d*, *e f*, respectively, fig. 2, and the effect was found to be greatest at *a b*, less at *e f* and *c d*. Finally, another slit was made along the middle line, and the electrodes were placed at *f* and *g*, fig. 3. The effect was qualitatively the same, but quantitatively less.

The question to settle now is, Whether this decrease is due to a decrease in the pure Hall effect? in the second effect? or in both? If we take the ratio $\frac{\Delta n}{n}$ for any one plate, we get a number which may be looked on as characteristic of that plate; it is independent of its dimensions, and depends only on its properties. If these are the same throughout—which we assume to be the case—and if we neglect the slight disturbances due to the fact that the temperature is not absolutely constant throughout the experiments, this number may be used to divide the transverse effect into its two constituents, and to give the relative values of these for any one plate, no matter how it is modified in size or shape. That is, we now apply the equation

$$c_1\left(\frac{\Delta n}{n}\right)^{\frac{1}{2}} + c_2\left(\frac{\Delta n}{n}\right)^{\frac{3}{2}} = \pm \mathrm{E} \qquad . \qquad . \qquad (3).$$

* *Sitz. bericht der kais. Akad. der Wissenschaft*, Wien, 1886.
† *Sitz. bericht der kais. Akad.*, Wien, 1887.

When this is done, we find that the decrease in the transverse effect, when the plate has the form fig. 3, is due to a decrease in both effects. Similarly, the decrease, as we move towards the ends, is also due to a decrease in both.

Another plate, VIIIA, was used next. The transverse electrodes were first placed in the middle, then at points 2 mm. from the ends, the transverse effect in the second position was the smaller. The results, treated as in IA, showed that the decrease was again due to a decrease in both effects.

PLATE VIIIA.

Length, . . . 44·0
Breadth, . . . 21·0 } mm. Temp. 15° C.
Thickness, . . 1·05

$$c_1\left(\frac{\Delta n}{n}\right)^{\frac{1}{2}} + c_2\left(\frac{\Delta n}{n}\right)^{\frac{3}{2}} = -\mathrm{E}.$$

Field.	Trans. Effect with Elect. in Middle.	Trans. Effect with Elect. near Ends.	$\frac{\Delta n}{n}$	$\frac{\sqrt{\Delta n}}{n}$	Electrodes in Middle. c_1	c_2	Electrodes near Ends. c_1	c_2
3,350	−·1616	−·1463	·0616	·2482	−·69	+·74	−·63	+·68
6,700	−·2371	−·2107	·1716	·4142	−·67	+·72	−·62	+·64
11,300	−·2612	−·2348	·3091	·5559	−·68	+·70	−·63	+·68
17,780	−·2377	−·2066	·5009	·7077	...	...	...	...

In Plate X. the electrodes were first soldered on to middle points of the sides, then to points 4 mm. from the end; the variation, however, was so small that no conclusion could be drawn as to its cause. This plate was also slit along the middle line, so that it had the form given in fig. 3, the results were qualitatively the same, but showed a decrease in E. This same plate, after being used for some time, showed a change in the field strength necessary to make the effect vanish. A higher field became necessary. The change was very small, and the application of equation 3 showed that the pure Hall effect had increased, while the second effect remained practically constant.

In a former paper it was shown that, in plates for which the transverse effect changes sign, the field strength at which the effect vanishes is raised when the plate is hammered or filed. To find what change in the pure Hall or in the second effect is concerned in this, the results obtained with Plate IB were examined; and it would appear that the pure Hall effect varies, while the second remains practically constant.

PLATE Ib.

Length,	44·7	mm.
Breadth,	20·8	
Thickness,	1·2235	

$$c_1\sqrt{\frac{\Delta n}{n}}+c_2\left(\sqrt{\frac{\Delta n}{n}}\right)^3=\pm E.$$

Field (about).	Trans. Effect.	$\frac{\Delta n}{n}$	$\sqrt{\frac{\Delta n}{n}}$	c_1	c_2
3,864	−·07693	·0408	·2019	...	...
8,694	−·02957	·1002	·3165	−·58	+4·8
16,284	+·15039	·1828	·4276	−·57	+5·1
19,320	+·21259	·2203	·4639	−·57	+4·7

The plate was next hammered and, approximately, the same field strengths used. The results were now—

$$c_1\left(\frac{\Delta n}{n}\right)^{\frac{1}{2}}+c_2\left(\frac{\Delta n}{n}\right)^{\frac{3}{2}}=\pm E.$$

Field.	Trans. Effect.	$\Delta n/n$ $\sqrt{\Delta n}/n$	c_1	c_2
As in last.	−·0126	As in last.	...	...
Do.	−·05166	Do.	−·73	+5·7
Do.	+·11249	Do.	−·72	+5·3
Do.	+·19027	Do.	−·73	+5·2

Finally, the plate was filed down, its thickness being reduced to ·665 mm. which, when the variation of resistance is taken into account, gives us

$$c_1=-·76\ c_2=+5·4.$$

Field.	Trans. Effect.	c_1	c_2
3,864	−·21699	...	...
8,694	−·13521	−1·52	10·9
16,284	+·17013	−1·50	10·4

The same results were obtained with Plate IX. It was first used when its thickness was 3·18 mm. The constants for this were—

$$c_1=-·18\ c_2=+·085.$$

Next it was filed down till a thickness 1·56 mm. was obtained. The constants were now—

$$c_1 = -\cdot 42 \quad c_2 = +\cdot 171.$$

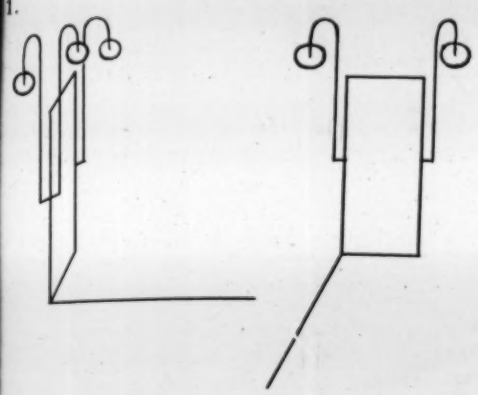
That is, the pure Hall effect has slightly increased; the second effect has remained constant.

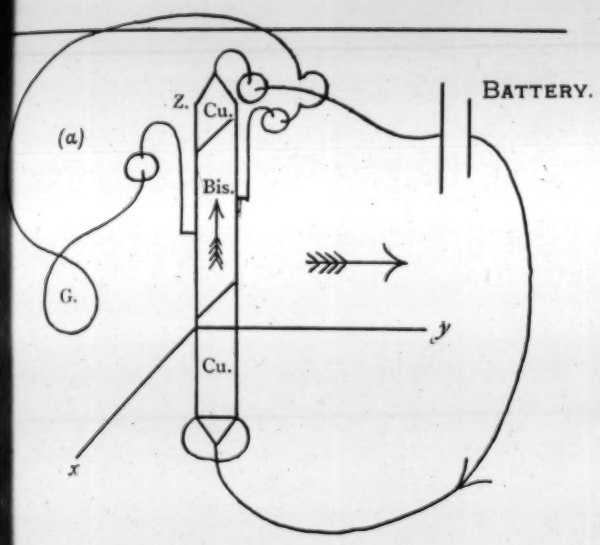
From the above we conclude that when a plate is slit along the middle line, as IA, the transverse effect changes in numerical value, but not in sign; the fact also that the effect decreases, but qualitatively does not change as we pass from the middle towards the ends, admits of a similar explanation. For, suppose we have a plate with electrodes (transverse) at a and b (fig. 4), the rotatory effect may be represented as in the figure. When the slits are made, several lines are interrupted (fig. 5); and when we approach the ends, the complete number of lines is given only on one side of the connecting line. The single safe conclusion to be drawn seems to be that the state of the plate, when it gives a transverse effect, is symmetric with respect to the middle line of its length.

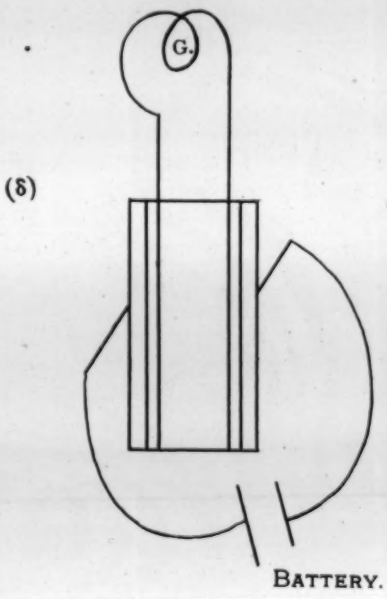
The causes of the pure Hall effect and of the second effect seem to be very intimately connected. Only by hammering or by filing a plate does it seem possible to vary one without varying the other.

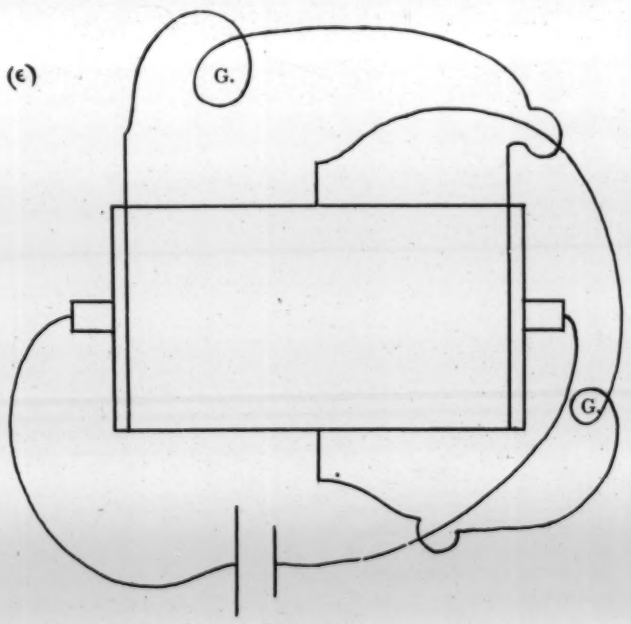
Evidently the relations obtained between the transverse effect and the resistance variation for the various plates do not allow us to compare the values of the constants in different plates, even when we use $\frac{\Delta n}{n}$; for this latter is a variable standard, depending on the plate and the temperature.

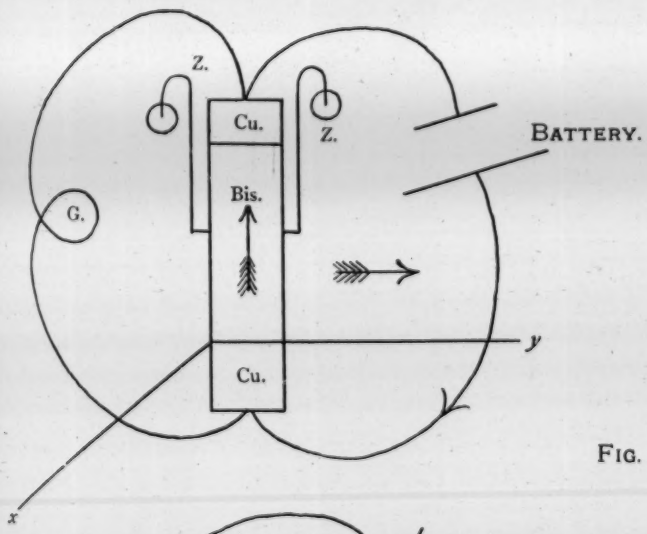
1.

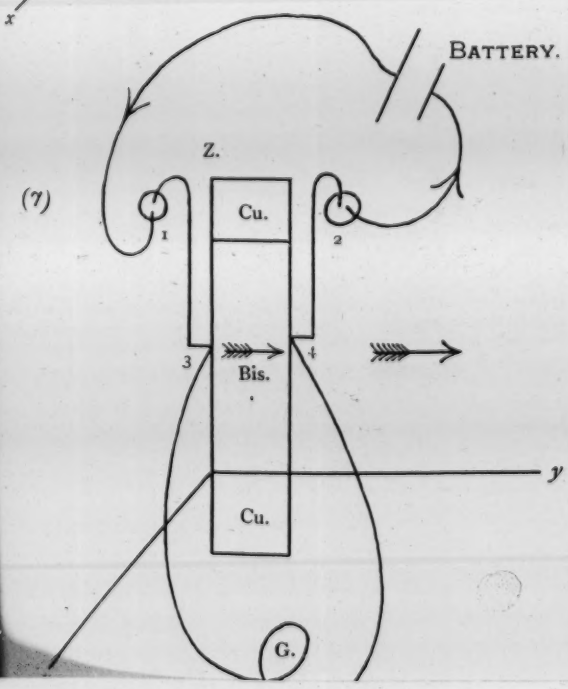












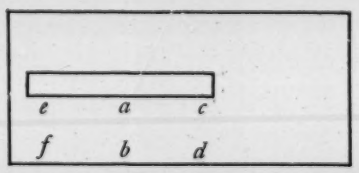


FIG. 2.

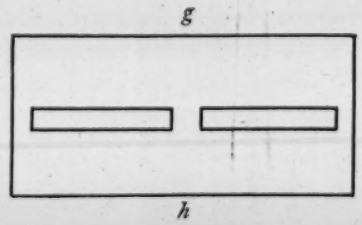


FIG. 3.

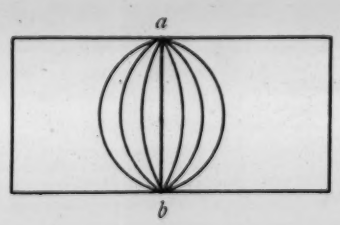


FIG. 4.

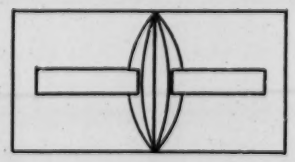


FIG. 5.

FIG. 6.

VIII.—*On the Comparative Histology and Physiology of the Spleen.*

By A. J. Whiting, M.D.* (With Three Plates.)

(Read 10th January 1893.)

CONTENTS.

PART I.

On the Comparative Histology of the Spleen.

Chapter I.

PAGE

The Supporting Framework of the Spleen, . . . 254
The Tunica Serosa—
in the Skate, Ling, and Cod, ... 255
in the Frog, Tortoise, Grass Snake, ... 255
in Birds and Mammals, ... 255
The Tunica Propria, the Trabeculæ, and the Hilar Sheath—
in the Skate, ... 255
in the Ling, ... 255
in the Frog, ... 256
in the Tortoise, ... 256
in the Grass Snake, ... 256
in the Hawk, ... 257
in the Rook, ... 257
in the Pig, ... 257
in the Ox, ... 257
in the Sheep, ... 258
in the Dog, ... 258
in the Cat, ... 258
in the Narwhal, ... 258
in the Porpoise, ... 258
in the Rabbit, Rat, and Guinea-pig, ... 259
in the Hedgehog, ... 259
in Man, ... 259
Summary, ... 260

Chapter II.

The Adenoid Sheath of the Splenic Arteries and the Splenic Follicles, ... 260
The Adenoid Sheath—
in the Cod, ... 262
in the Skate, ... 262
in the Frog, ... 262
in the Tortoise, ... 262
in the Grass Snake, ... 263
The Splenic Follicles—
in the Rook, ... 263
in the Ox, ... 263
in the Sheep, ... 264
in the Pig, ... 264
in the Cat, ... 264
in the Dog, ... 265
in the Porpoise, ... 265

PAGE

The Splenic Follicles (*continued*)—
in the Narwhal, ... 265
in the Rabbit, ... 266
in the Rat, ... 266
in the Guinea-pig, ... 266
in the Hedgehog, ... 267
in Man, ... 267
Summary, ... 268

Chapter III.

The Ellipsoidal Sheath of the Splenic Arteries and the Splenic Ellipsoids, ... 269
in the Skate, ... 269
in the Cod, ... 269
in the Frog, ... 269
in the Tortoise, ... 270
in the Grass Snake, ... 270
in the Hawk, ... 270
in the Rook, ... 270
in the Pigeon, ... 271
in the Ox, ... 271
in the Sheep, ... 271
in the Pig, ... 272
in the Dog, ... 272
in the Cat, ... 272
in the Porpoise and Narwhal, ... 273
in the Rabbit, Rat, Mouse, and Guinea-pig, . . 273
in the Hedgehog, ... 273
in Man, ... 273
Commentary, ... 273
Summary, ... 274

Chapter IV.

The Splenic Pulp, ... 275
in the Dog, ... 275
in the Skate, ... 276
in the Cod and Ling, ... 276
in the Frog, ... 277
in the Tortoise, ... 278
in the Grass Snake, ... 279
in the Hawk and Pigeon, ... 279
in the Rook, ... 279
in the Pig, Sheep, and Ox, ... 279
in the Dog, ... 281
in the Cat, ... 282
in the Porpoise, ... 284
in the Narwhal, ... 285
in the Rabbit, ... 285

* This paper consists of the principal part of a thesis presented to the University of Edinburgh in 1892, for the degree of Doctor of Medicine, which was awarded a gold medal and an equal share of the Goodsir Prize.

PAGE

The Splenic Pulp (*continued*)—
in the Rat, ... 286
in the Mouse, ... 287
in the Guinea-pig, ... 288
in the Hedgehog, ... 288
in Man, ... 289
Commentary, ... 293
Summary, ... 293

PART II.

ON THE PHYSIOLOGY OF THE SPLEEN AND BLOOD FORMATION.

CHAPTER V.

Historical Epitome, ... 296
Description of Leucocythæmic Spleen, ... 298

PAGE

On Artificial Anæmia in Dogs, ... 298
Description of Spleens of three Anæmic Dogs, . . . 301
Two Experiments on Anæmia in Dogs, ... 302
Results of Experiments, ... 309
Summary of Effects of Hæmorrhage, ... 310
On Artificial Anæmia in the Rabbit and Description of Spleen of Anæmic Rabbit, ... 310

PART III.

METHODS—BIBLIOGRAPHY—DESCRIPTION OF FIGURES.

CHAPTER VI.

Methods, ... 311
Bibliography, ... 314
Description of Figures, ... 316

PART I.

ON THE COMPARATIVE HISTOLOGY OF THE SPLEEN.

CHAPTER I.

The Supporting Framework of the Spleen.

The following general description of the capsule, trabeculæ, and sheaths of the splenic vessels is based on the examination of the spleen of *the Kitten.*

The Tunica serosa consists of a single layer of somewhat thick endothelial cells, which is continuous with the peritoneal lining of the body cavity, and in addition of a thin layer of very finely fibrillated connective tissue that lies immediately subjacent to the endothelial layer.

The Tunica propria differs from a true capsule in that it blends along its whole under surface with the splenic parenchyma, from which it cannot be detached without tearing the splenic substance.

It is composed of two layers, one consisting of ordinary connective tissue and the other of muscular tissue. The more superficial layer is formed of interlacing bundles of white fibrous tissue, between which are a few lymphoid cells, and of many strands of elastic tissue, which, when stained with picrocarmine, appear as highly refractile yellow bands or dots according as they are seen longitudinally or in transverse section. About midway in the thickness of the tunica propria spindle-shaped muscle fibre cells begin to appear. They increase in number until, at the inner fourth of the capsule, they form a continuous layer principally directed transversely to the long axis of the spleen. Above the circular muscular layer, as well as below it, there are a few longitudinally arranged muscle fibre cells.

From the circular muscular layer of the capsule *the trabeculæ* spring as gently curved bands, and are themselves composed of non-striped muscle.

As the artery enters the spleen, along with the nerves, at the hilus, it receives a

somewhat thick sheath from the tunica propria, which is therefore composed internally of white fibrous tissue and externally of unstriped muscle. This investment may be called the *capsular* or *hilar sheath*. The external layer is almost immediately reinforced by the junction of the muscular trabeculæ. The fibrous tissue next the outer wall of the artery is finer, looser, and contains more lymphoid cells than that near the external muscular layer, and it is apparently derived, in part at least, from the sub-endothelial connective tissue of the tunica serosa, which is more abundant in the neighbourhood of the hilus.

The splenic vein, while accompanied by the artery and nerves near the hilus and internal to it, is invested by a somewhat thin covering of fibro-muscular tissue derived from the hilar sheath. In the interior of the spleen, when separate from the artery, the vein runs within or at the side of a trabecula. The veins are conducted to the hilar sheath by the trabeculæ, where they are surrounded by dense muscular or fibro-muscular tissue without the intervention of a looser fibrous layer.

The Tunica Serosa.

The Tunica serosa in all animals consists of a single layer of cells that individually vary in shape in different animals. The endothelial cells covering the spleen of *the Skate* are columnar in shape. In *the Ling* and *Cod* they are low columnar or cubical. In *the Frog* and *Newt* they are somewhat shorter than in the bony fish, and approach a pointed oval shape. In *the Tortoise* they are a little lower than in the Amphibia. In *the Grass Snake* they are still more flattened than in the tortoise, but are at the same time somewhat thick. In *adult Birds* and *Mammals* they are squamous, but in *fœtal* mammals they are cubical, and *during the first few weeks of extra-uterine life* they are thick, but flattened like those of the Amphibia and Ophidia.

Thus the cells of the tunica serosa, as the scale is ascended from fishes to mammals, become gradually more flattened out.

The Tunica Propria, the Trabeculæ, and the Hilar Sheath.

In *the Skate* the tunica propria is principally composed of white fibrous tissue arranged in large loosely interwoven bundles, between which there are a few lymphoid cells. In the deeper portion of the capsule there are some spindle-shaped muscle fibre cells which do not form a distinct layer. In the substance of the capsule, near the parenchyma, there are a few narrow venous sinuses. There are no true trabeculæ. In addition to the capsule, the only representative of a supporting framework is the loose fibrous tissue, derived from the tunica propria, that accompanies the vessels through the hilus.

In *the Ling* the tunica propria appears to be composed of three layers. The outermost layer consists of loosely arranged spindle-shaped cells, that stain deeply with hæmatoxylin and closely resemble connective tissue corpuscles. The intermediate layer is

relatively thick, and formed of interlacing bundles of white fibrous tissue containing many lymphoid cells and many large blood-vessels and nerves. The innermost layer is denser and thinner than the others (it is about one-fifth the thickness of the intermediate layer), and is composed of unstriped muscle fibre cells that are rendered conspicuous by staining deep-pink with eosine.

Joining the under surface of the lower muscular layer are delicate, open, fibrous strands that consist mainly of spindle cells, many of which are muscular. These strands are continuous with others that form a nearly regular meshwork, and which divide the parenchyma into a series of polygonal areas. In the middle of each area is an arteriole or a capillary blood-vessel enveloped in its special sheath.

The hilar sheath is very strongly developed in the teleostean spleen; its peripheral portion is distinctly muscular. The fibrous strands that bound the polygonal areas are apparently derived from this outer portion of the hilar sheath.

In *the Frog* the tunica propria consists of white fibrous tissue arranged more or less distinctly in bundles. Scattered throughout its substance are spindle-shaped fibre cells, which are almost certainly muscular. These are specially noticeable immediately under the tunica serosa and also adjoining the parenchyma, as in the capsule of the cod's spleen. Imbedded within the substance of the tunica propria are numerous very large venous sinuses which are connected by somewhat large branches with the venous sinuses of the pulp. Around the capsular blood-sinuses the spindle-shaped fibre cells form a comparatively thick layer which stains pink with eosine, and is undoubtedly muscular. There are no true trabeculæ. The only representative of the supporting framework in the interior of the spleen is a relatively small amount of fibrous tissue forming a sheath for the blood-vessels.

In *the Tortoise* the tunica propria consists of two layers, the outer composed of white fibrous tissue staining faintly blue with hæmatoxylin, and the inner composed of unstriped muscle staining deeply with eosine and picric acid. The outer looser layer contains a few large, clear, faintly stained lymphoid cells; in the inner layer immediately subjacent to the outer layer there are venous sinuses somewhat larger than those in the frog, and like them surrounded by muscle. There are no true trabeculæ. The arteries run in a thick fibrous sheath, which externally is strongly muscular, corresponding with the inner layer of the capsule. Immediately surrounding the artery is a layer of loose areolar tissue containing a few clear lymphoid cells corresponding, therefore, with the superficial layer of the capsule.

In *the Grass Snake* the tunica propria is composed of dense fibro-muscular tissue. It consists chiefly of white fibrous tissue towards the surface, while deeper it is almost entirely muscular. Within the muscular portion large venous sinuses are very numerous, as in the skate, frog and tortoise. Where the muscular portion joins the parenchyma, its fibres separate so as to form elongated meshes in which are rows of lymphoid cells. Four broad trabeculæ-like processes, somewhat wedge-shaped, composed of tissue resembling that of the deeper portion of the tunica propria, but more loosely arranged,

pass from the under surface of the capsule into the substance of the spleen to join a large fibrous core. Both processes and core contain wide venous sinuses which communicate with each other and with those of the capsule. This supporting framework appears to represent a strongly developed hilar sheath rather than a true trabecular system.

In *the Hawk* the tunica propria is composed of a loose network of white fibrous tissue, in the meshes of which are a few lymphoid cells, and contains, irregularly interspersed, many spindle-shaped muscle fibre cells. There are no trabeculæ. There is a somewhat strongly developed hilar sheath, a considerable proportion of which consists of non-striped muscle.

In *the Rook* the tunica propria may be divided into three layers; first, an outer thin layer of white fibrous tissue, containing many elastic fibres; second, an intermediate thin muscular layer, the fibres of which run longitudinally; and third, a transverse muscular layer, four or five times thicker than either of the other layers. Between the two muscular layers is a row of lymphoid cells. There are no true trabeculæ. The arteries and veins are invested by a thick hilar sheath, the outer part of which is purely muscular.

In the spleen of *the Pig* the tunica propria is composed almost entirely of non-striped muscle. There is externally a thin layer of white fibrous tissue, and the rest is muscle, which is mainly arranged in two layers—an outer layer of transverse fibres and an inner thicker layer of longitudinal bundles; but there are also many strands arranged obliquely. From the deeper longitudinal layer massive muscular trabeculæ arise, which, passing inwards, anastomose to form a very coarse network. From the periphery of these large trabeculæ, and from the under surface of the capsule between their points of attachment, there are given off a few microscopic trabeculæ, which form a secondary network within the meshes of the larger network. Some of these are attached to the vascular sheaths, others end in the pulp apparently by becoming connected with its reticulum. The venous trunks, before they join the arteries, are intimately connected with the larger or primary trabeculæ. The hilar sheath has a very strongly developed muscular layer which unites with the trabeculæ. A noticeable peculiarity in this spleen is that the arteries divide into smaller branches within the hilar sheath.

In *the Ox* the arrangement of the tunica propria resembles closely that in the pig. The layer of loose connective tissue under the tunica serosa is thicker, and contains more connective tissue corpuscles. The deeper muscular portion, as in the pig, is composed mainly of two layers, a superficial layer transverse and relatively thin, and a deep layer longitudinal and very thick; but oblique fibres are by no means so numerous as in the pig. Springing from the deeper layer, large muscular trabeculæ pass into the parenchyma, and from them, as well as from the under surface of the capsule, numerous microscopic trabeculæ arise and scatter themselves throughout the pulp, and cease only around the termination of the arteries. These microscopic trabeculæ are much more numerous and much stronger than in the pig's spleen. A strong hilar sheath envelopes the blood-vessels and nerves, and its outer portion is composed

of a remarkably thick muscular layer. Conspicuous within the hilar sheath are numerous large nerve trunks. Sometimes a nerve may be seen to run alongside of or within a trabecula, unaccompanied by any vessel.

In the spleen of *the Sheep* the general arrangement is similar to that in the pig and ox, but the muscular bundles are usually more loosely arranged than in them, and the microscopic trabeculæ are less strongly developed than in the ox, but more strongly than in the pig.

In *the Dog* the tunica propria is composed of two nearly equal portions. The outer half consists of interlacing bundles of white fibrous tissue containing numerous connective tissue corpuscles and elastic fibres with a few lymphoid cells. The inner half is composed of unstriped muscle mostly arranged in two layers, the outer of which is transverse and the inner longitudinal. In the spleen of the puppy muscular fibre cells are sparse, and occur only in the deeper part of the capsule. The trabeculæ, which are almost entirely muscular, are both numerous and large, but in the puppy they are much less numerous. The majority of them are tunnelled by veins. The artery is immediately surrounded by a somewhat thick layer of fine connective tissue, outside which is a strong cylindrical sheath of muscle.

In *the Cat* the greater proportion of the tunica propria consists of unstriped muscle, externally there is merely a thin layer of white fibrous tissue. Most of the muscle fibres are arranged transversely, so as to form a circular coat, but above as well as below this there are a few strands of longitudinally arranged fibres. The trabeculæ, which are strongly developed, spring from the thick circular layer of the capsule, and are composed almost entirely of muscle. The hilar sheath is also well developed (Plate I. fig. 1). Its outer muscular layer is the thicker. Shortly after the artery has passed through the hilus, its loose connective tissue sheath, derived from the inner layer of the hilar sheath, contains a few lymphoid cells. In the newly-born kitten the capsule has no distinct muscular layer, and the trabeculæ are small and sparse.

In *the Narwhal* the tunica propria is composed of two layers; a superficial thicker layer consisting of wavy bundles of white fibrous tissue with many elastic fibres scattered at intervals, and a deeper thinner layer consisting chiefly of non-striped muscle. There are no true trabeculæ. Usually the veins are immediately surrounded by the parenchyma, but occasionally there may be seen a few strands of unstriped muscle supporting the larger veins. The vessels are accompanied into the interior of the organ by a large amount of fibrous tissue, containing in its meshes numerous lymphoid cells. Towards the periphery of the hilar sheath, unstriped muscle fibre cells may generally be observed, among which there may sometimes be seen triradiate muscle fibre cells similar to those found in the urinary bladder of Amphibia.

In *the Porpoise* the tunica propria is much thicker on the side that corresponds with the concave or hilar surface of the spleen. On the convex surface it may be roughly divided into two layers: a superficial layer composed of white fibrous tissue, and a deeper layer composed almost entirely of unstriped muscle. On the hilar surface it

is thickened by the addition of an intermediate layer, composed of areolar tissue, which contains many arteries and many relatively large thin-walled veins. The latter feature reminds one of the intracapsular venous sinuses in cartilaginous fishes, in the Amphibia, in the Chelonia, and in the Ophidia. This intermediate layer also contains fat cells and numerous strands of unstriped muscular fibre. The trabecular system is but slightly developed. The trabeculæ, which are apparently derived chiefly from the vascular sheaths, are in the form of flattened bands of long muscle fibres, each band so loosely arranged that elongated meshes result, in which numerous lymphoid cells are found. The hilar sheath which surrounds the larger arteries and veins is in the form of a somewhat thick investment of fibro-muscular tissue.

In *the Rabbit, Rat, and Guinea-pig* the tunica propria consists mainly of white fibrous tissue, containing some connective tissue corpuscles and a few lymphoid cells. There is a small amount of unstriped muscle, chiefly in the deeper portion of the capsule, which does not amount to a layer in the rabbit and the rat, but in the guinea-pig forms about the inner fifth of the capsule; most of the fibres are transverse, some are longitudinal, and these are more numerous near the hilus than elsewhere. The tunica propria contains a considerable number of elastic fibres which are especially numerous in the rat. The trabeculæ are somewhat thick but not dense. They are composed of a mixture of white fibrous tissue and of unstriped muscle, and are relatively more muscular than the capsule, which is accounted for by their being derived from its deeper part. In the rat the trabecular framework is more strongly developed, and the trabeculæ contain a greater proportion of muscle than in the rabbit and guinea-pig. The hilar sheath is, in each case, feebly developed, and contains little muscle.

In *the Hedgehog*, as in the Rodentia, the tunica propria consists chiefly of white fibrous tissue. There is a thin layer of muscle next the parenchyma, and there are a few muscle fibre cells scattered throughout the thickness of the capsule. Contrasting with the scarcity of muscle there is an abundance of elastic tissue. The trabecular system is somewhat more strongly developed, and contains more muscle, than in the Rodentia. The trabeculæ break up into small secondary ones that resemble the microscopic trabeculæ found in the spleen of the Ungulata. The hilar sheath is well developed. There is a well-developed muscular outer layer, between which and the outer surface of the artery lies a considerable quantity of areolar tissue containing lymphoid cells, and forming the early stage of an adenoid sheath. This does not appear immediately after the arteries have separated from the veins, but after their second bifurcation. (Plate I. fig. 2.)

In *the Human Spleen* the tunica propria is composed almost entirely of white fibrous tissue. There is a small amount of yellow elastic tissue associated with a little muscle. The spindle-shaped muscle fibre cells are practically confined to the deeper portion of the capsule, and are slightly more numerous near the origin of the trabeculæ. The trabecular framework is only slightly developed. The trabeculæ consist chiefly of white fibrous and elastic tissue. They have only a small amount of muscle, but follow

the rule in being relatively more muscular than the capsule. The hilar sheath is well developed. Its outer portion is somewhat strongly muscular. The muscle fibre cells are arranged both longitudinally and transversely.

Summary regarding the Supporting Framework of the Spleen.

1. The variation in the supporting framework of the spleen appears to be mainly in two directions, one in the degree of its muscularity, and the other in the degree of the development of the trabecular system.

2. I would here emphasise the fact that the hilar sheath around the vessels is muscular as well as the trabeculæ, and, as I have several times already implied, its muscularity varies with that of the capsule as a whole, and is therefore in the aggregate less than that of the trabeculæ, which resemble the deeper muscular portion of the tunica propria. KLEIN * and BANNWARTH † have noticed the presence of muscle in the hilar sheath.

3. As the supporting framework of the spleen becomes less strongly developed in the higher animals, and as its muscularity decreases, the elastic element increases.

4. I think it is important to regard the hilar sheath as outside the essential splenic substance, as, in fact, an inflection of the capsule.

5. The trabecular system proper appears to be peculiar to the Mammalia; where it is represented in the lower vertebrates it probably corresponds with the hilar sheath and, except in the Ophidia, is feebly developed.

6. Among mammals the trabecular system reaches its highest development, as far as I have observed, in the Carnivora; its lowest, in the Cetacea.

7. Unstriped muscle occurs in the framework of all the spleens that I have examined. At its minimum in the fish, it gradually increases in amount as the scale is ascended through the amphibians, the reptiles, the birds, to the mammals, and reaches its maximum among the Mammalia in the Ungulata or Carnivora, then gradually decreases through the Cetacea and the Rodentia (rising slightly, however, in the hedgehog) to Man.

CHAPTER II.

The Adenoid Sheath of the Splenic Arteries and the Splenic Follicles.‡

As the splenic artery and nerves pass through the hilus of the spleen they are ensheathed by the inflected capsule. The sheath consists of three strata: next the artery is a thin layer of loose areolar tissue, derived, in part at least, from the subperitoneal connective tissue, and probably in part from the tunica adventitia of the artery, containing a few lymphoid cells; then comes a layer of denser white fibrous tissue, derived from the outer layer of the capsule, containing a considerable number of connective tissue

* KLEIN (16), p. 367. † BANNWARTH (26).

‡ The following general description is based on the examination of the spleen of *the Kitten*.

corpuscles, a few lymphoid cells, and some strands of yellow elastic tissue; and externally is a layer of unstriped muscle derived from the inner layer of the capsule.

Near the hilus this sheath surrounds both the artery and the vein, the latter having pierced the sheath at some distance internal to the hilus. Shortly after the artery has separated from the vein, there occurs within the hilar sheath a proliferation of lymphoid cells, which seems to begin in the innermost stratum—the layer derived from the subserous connective tissue. As the artery becomes smaller, the lymphoid cells increase greatly in number, and the sheath is represented by a small amount of white fibrous tissue together with the external muscular layer, which is itself much thinner. The arterial branch, thus surrounded by loosely arranged lymphoid cells, and externally by the remnant of the hilar sheath, divides in a dichotomous manner. The branches that result are similarly ensheathed, except that the investment of adenoid tissue varies in thickness, so that it resembles in some degree a nodose root, and that the remnant of the hilar sheath is thinner, and consists almost entirely of unstriped muscle.

The nodosities of the adenoid sheath constitute the splenic follicles or Malpighian bodies, and the extension of the hilar sheath forms for them a capsule-like covering which is contractile, and probably also highly elastic. In a section of a follicle, whether the artery be cut transversely, obliquely or longitudinally, the cells of which the peripheral layer is composed always appear spindle-shaped. The obvious explanation of this is, that as spindle-shaped muscle fibre cells run in all directions over the follicle, adapting themselves to its spherical contour, those fibres alone that are in the plane of the section are seen with characteristic fusiform shape, while those cut obliquely or transversely appear as inconspicuous dots. This peripheral zone consists usually of two, three, or four loose layers of fibres; and that it is continuous with the outer muscular layer of the hilar sheath is clearly seen when a longitudinal section of the artery and follicle is examined. Springing from the artery thin-walled capillaries run among the lymphoid cells, and they are more numerous, and consequently more conspicuous, towards the periphery of the follicle.

The substance of the follicle consists of lymphoid cells, most of which are large and uninucleated, contained in the meshes of an adenoid reticulum. Near the centre of the follicle, a few larger uninucleated or multinucleated lymphoid cells may be seen, and towards the periphery there is a narrow belt of small uninucleated lymphoid cells. Occasionally very large protoplasmic cells, four or five times the size of the largest lymphoid cells, are found near the centre of the follicle. Their protoplasm is coarsely granular and stains very deeply with eosine. Some of these cells appear to be non-nucleated; in others there is a single nucleus at the margin of the cell, and they often exhibit round vacuoles.

The intrafollicular reticulum consists of delicate branching threads, that anastomose at irregular intervals. Upon the nodes of the network large, oval, connective tissue cells are placed. The meshes vary in size and the threads in fineness. The meshes are closer and the threads stronger towards the periphery. In addition to this reticulum there is

an intercellular substance of white or pearly appearance, which, after injection of the spleen through the artery with silver nitrate solution, appears as a brown network, in each mesh of which is a lymphoid cell. This network differs, therefore, from the adenoid reticulum in being regular in size of mesh, and in being equally distinct at all parts of the follicle.

The adenoid sheath of the splenic arteries does not show any nodular swellings in the fish, amphibians, or reptiles, nor in some birds. In *the Cod*, after the splenic arteries have become somewhat diminished in size, while they are still accompanied by the branches of the splenic vein, their thick fibrous coat becomes infiltrated with lymphoid cells. Except around the largest arterial branches, the matrix of this coat is not strongly fibrous, but resembles very fine areolar tissue or mucous tissue. The lymphoid cells are small, sparse, and stain deeply with hæmatoxylin. Among them red blood-corpuscles are occasionally seen, indicating the presence of capillaries. The artery with its adenoid sheath, together with the vein, and nerve trunks if present, are surrounded by the hilar sheath, at the periphery of which a few muscle fibre cells are seen.

In *the Skate* there are groups of cells in relation with the walls of the splenic arteries. Each group is nodular and not unlike the splenic follicle of the higher vertebrate, with part at least of which it is probably homologous. They are conspicuous from their reddish-brown colour, and, while some are plainly connected with the arterial wall, others, which are cut at one side of the artery, appear isolated. The cells vary considerably in size—the smallest are about the size of an average lymphoid cell, and the largest are five or six times larger. The larger cells are each situated in a cell-space, and contain one or two nuclei imbedded in reddish-brown granular protoplasm, while the smaller consist of a single spherical nucleus surrounded by a mere rim of protoplasm. Many of the nuclei show evidence of division. The cells appear to be arranged in columns. Surrounding each nodule is a belt of fibrous tissue derived from the hilar sheath, and outside that is a zone of lymphoid cells which fades away into the surrounding pulp.

In the spleen of *the Frog* there is a grouping of lymphoid cells around the artery, without any localised accumulation. Loosely arranged clusters of cells are especially noticeable immediately under the capsule, most, if not all, of which are sections of the adenoid sheath. There is apparently no peripheral zone of fibrous tissue; but among the cells were seen coloured blood-corpuscles contained within capillaries.

In the spleen of *the Tortoise* the pulp and the adenoid tissue are nearly equal in amount: the latter is more abundant near the capsule, the former near the centre. The lymphoid tissue follows the course of the arteries in very broad bands, and nowhere shows localised accumulation. Not the arteries alone, but also the veins are surrounded by adenoid tissue as in the spleen of the skate. The artery while of considerable calibre is closely surrounded by a thin layer of very delicate fibrous tissue, outside which is a comparatively thick layer of adenoid tissue. As the artery becomes smaller the adenoid

sheath becomes thinner, and the connective tissue sheath thicker, until the lymphoid sheath disappears when the latter persists as a thick, almost granular, investment of a thin-walled vessel. It contains several large, round or oval, clear cells, which stain faintly with hæmatoxylin. The capillaries are large, but not numerous, and therefore do not form a close network. The cells are contained in the meshes of a delicate fibrous reticulum, which seems to be continuous with that of the adjoining pulp. They are mainly of three kinds :—(1) Small, angular, deeply blue-stained lymphoid cells, which fill the greater part of the adenoid tissue ; (2) much less numerous cells, consisting of a large vesicular nucleus, surrounded by granular pink-stained protoplasm, that varies in amount in different cells. Such cells may, however, have a horse-shoe shaped nucleus, or two, three, or more somewhat large nuclei, or sometimes eight to twelve small, deeply blue-stained nuclei, in which case there is only a small amount of intermediate protoplasm ; (3) pink-stained granular cells occurring in clumps, which are situated in the delicate fibrous tissue that surrounds the artery. The characters of the cells, and their grouping, recall similar appearances found in the skate's spleen, but the cells in the skate are much larger.

The spleen of *the Grass Snake* shows a cellular cortex and a fibrous medulla. The former is composed of four wedge-shaped masses of lymphoid tissue, the apex of each pointing to the centre. The latter consists of a four-rayed core of fibrous tissue, which contains large ramifying blood-sinuses, each pyramidal ray separating two wedges of adenoid tissue. Thus the base of the wedge is placed upon fibro-muscular tissue containing blood-sinuses, its sides are bounded by fibrous bands that contain blood-sinuses, and its blunt apex is imbedded in fibrous tissue that contains blood-sinuses. About the middle of each wedge there is a comparatively small artery, and running between the lymphoid cells are large, thin-walled, much branched capillaries that anastomose with each other to form a network, and open into the venous sinuses that are contained in the surrounding fibrous tissue. The cells of the adenoid tissue resemble those already described in the spleen of the tortoise. The protoplasmic cells are specially noticeable immediately outside the capillary wall.

The Splenic Follicles make their first appearance in birds, but they do not occur in all ; for instance, they are absent from the spleen of the hawk.

In *the Rook* the special artery of the follicle, as well as the capillaries, are of remarkably large size. The follicles are almost invariably situated on one side of the artery, and not round it. Around the follicles there is a strong belt of muscle, which consists of two or three interlacing layers, and which may very clearly be seen to spring from the hilar sheath. (Plate I. fig. 3.) The cells are of two kinds :—(1) Large protoplasmic corpuscles having a single nucleus—similar cells occur plentifully in the pulp surrounding the follicles ; and (2) ordinary small lymphoid cells. These two kinds are indiscriminately mixed throughout the follicle. There is a delicate adenoid reticulum.

In the spleen of *the Ox* the follicles are numerous and conspicuous. Two small arteries may occasionally be seen in one follicle, and fairly large capillaries run in its

substance. The intrafollicular reticulum is fibrous but not very strongly developed. Many of the follicles possess a large-celled central area—the germinal centre of FLEMMING—which tends to fall away from the section. The cells of the follicle are of two kinds:—(1) Small, deeply stained lymphoid cells, which are often collected in clumps, and the clumps sometimes appear to be surrounded by a capsule; and (2) large, faintly stained cells, leucoblasts, grouped near the centre, but also occurring sparsely among the smaller ones, which consist of a large vesicular nucleus surrounded by a varying amount of finely granular protoplasm, that occasionally contains yellow pigment grains. There is a distinct zone of fine spindle-shaped muscle fibre cells, in two or three layers, bounding the follicle; and outside that is a broad belt of tissue showing characters intermediate between those of the pulp on the one side and those of the follicle on the other, and is, in fact, the pulp containing the lymphoid cells, small and uninucleated, part of which have probably been pushed out by the cellular proliferation within the follicle, and part squeezed out by the contraction of the peripheral muscular layer. Although these cells are small, they are apparently somewhat larger than those in the outer part of the follicles.

In the spleen of *the Sheep* the continuous adenoid sheath of the artery, along the course of the artery, between the follicles and the hilus, is very well developed. It is bounded externally by the thick muscular layer of the hilar sheath. The structure of the follicle resembles very closely that in the ox. But the artery is apparently of larger calibre, the capillaries are slightly larger, and the intrafollicular reticulum is somewhat more strongly developed. The lymphoid cells show the same division into zones, a large-celled germinal centre, a small-celled peripheral zone, and an extrafollicular aureola.

In the spleen of *the Pig* the follicles are not quite so numerous as in the ox and sheep, and they are still less sharply defined from the surrounding pulp. Sometimes sections of three or four arteries may be seen in one follicle; moreover, the artery may often be seen to branch within the continuous adenoid sheath without any division of the hilar sheath. In structure the follicles are almost identical with those in the ox and sheep; the intrafollicular reticulum appears, however, to be more strongly developed. In the spleen of *the young Pig* the peripheral zone of muscle is more distinct than in the adult, as also is its origin from the hilar sheath.

In *the Cat* the follicles are more numerous and larger, relative to the size of the spleen, than they are in the Ungulata. The intrafollicular capillaries form a very distinct network, and they may frequently be traced into the spaces of the pulp. The cells of the follicle in the adult cat are clearly divisible into two zones. In a central area, where the capillaries are most numerous, they are comparatively large, although they vary considerably in size; some of them are uninucleated and others are multinucleated. The nuclei always possess a nucleolus, and the cells a definite outline. Some of the smaller central cells show evidence of division by transverse fission. The largest cells in the follicles are scattered and isolated, each contained in a cell space.

Their protoplasm stains very deeply with eosine, and they usually possess a single, oval, somewhat small nucleus. In the outer zone the cells are smaller, more nearly uniform in size; they stain more deeply with hæmatoxylin and closely resemble free nuclei. They are arranged with considerable regularity in circular lines, the outermost circles being separated by long connective tissue strands derived apparently from the hilar sheath. At the periphery of the follicle is a zone of spindle-shaped muscle fibre cells, similar to the zone already described in the kitten, only not quite so distinct.

In the spleen of *the Dog* the follicles are much like those in the cat's spleen. The special artery is immediately surrounded by a thick fibrous sheath, which seems to represent the original tunica adventitia of the artery. The intrafollicular reticulum is feebly developed. The follicular cells are divisible into three zones: the germinal central cells and those of the peripheral zone resemble the cells described in the cat's spleen; the intermediate zone is composed of cells like those of the peripheral zone, but slightly smaller. There is a limiting belt of spindle-shaped muscle fibre cells, which is more prominent in the spleen of the puppy than in the adult dog. In the spleen of *the Puppy* nearly all the cells of the follicle are like the central germinal cells; smaller cells are found in a narrow ring at the periphery of the follicle, and plentifully in the pulp outside it. It seems to be the rule that the follicular cells are divisible into three zones in the adult alone.

In the spleen of *the Porpoise* there are numerous accumulations of lymphoid cells, but they are not sharply defined. The intrafollicular capillaries are somewhat large and very conspicuous. They may occasionally be clearly seen to open into the spaces of the pulp. The lymphoid cells do not show any distinct division into zones. They resemble the cells in the germinal area of other adult, or those of the entire follicles of the young mammal. In many of the cells the nucleus is surrounded by a layer of protoplasm that stains deeply pink with eosine; and very large cells similar in character may sometimes be seen near the middle of the follicle. The follicles have apparently no fibrous limiting layer. Large venous trunks form a kind of boundary for them. In several points of structure this spleen resembles the reptilian spleen; in the large venous spaces of the capsule, in the diffuse adenoid tissue partially surrounded by venous channels, and in the large size of the capillaries within the adenoid tissue. The macroscopic appearances of the spleens of the tortoise and porpoise are similar, and both are developed in the mesentery of the small intestine.

In the spleen of *the Narwhal* the follicles are numerous but small, and the cells that form them, being of large size, are in comparatively small number. The artery divides simultaneously into a number of arterioles which run a nearly parallel course. There may be as many as eleven branches, and together they produce a characteristic brush-like appearance. A similar, although less pronounced, arrangement obtains in the pig's spleen. This bundle of vessels is contained in a matrix of fibrous tissue, that contains a few lymphoid cells, and forms a rudimentary adenoid sheath. When the arterioles separate from each other, lymphoid cells accumulate in the fibrous tissue

matrix, and wide thin-walled capillaries run among them. This fibrous matrix is apparently derived both from the tunica adventitia of the artery and from the inner layer of the hilar sheath. The follicular cells appear to be of four kinds: (1) The majority are large round cells consisting of a round, deeply stained nucleus surrounded by a rim of protoplasm; (2) smaller round cells, like free nuclei, staining even more deeply with hæmatoxylin; (3) cells the largest of all, pale and granular, containing a faintly stained vesicular nucleus; (4) cells similar to the last, but found only in some follicles, containing numerous yellow pigment grains. At the periphery of the follicles is a remarkably distinct zone of muscle, composed of two or three layers of spindle cells.

In the spleen of *the Rabbit* the follicles are numerous and well localised. The network of capillaries is unusually conspicuous. Some of the follicles in the adult spleen contain small but distinct germinal centres. The follicular cells are clearly divisible into three concentric areas. The largest cells are, as usual, in the central area, the smaller are in the peripheral zone, and the smallest are in the narrow intermediate zone. The germinal centre is marked off from the intermediate zone by a ring of fibrous tissue containing spindle-shaped nuclei. The cells in it are of four kinds: (1) Large cells, consisting of a big vesicular nucleus that stains blue with hæmatoxylin, and a small amount of peripheral protoplasm that stains pink with eosine; each of these is usually enclosed in a cell space: (2) somewhat smaller cells with a round, comparatively small and deeply stained nucleus surrounded by a relatively large amount of protoplasm; occasionally seven or eight of such cells are found packed together in a cell space: (3) large pigment cells, occasionally seen: (4) small, deeply stained lymphoid cells, possessing a very small amount of protoplasm, if any, around a nucleus which contains a nucleolus. The last kind are specially numerous near the periphery of the germinal centre, and are evidently identical with the cells of the intermediate zone. The capillaries in the central area are larger than those in the other parts of the follicle. Surrounding the follicle is a zone of spindle-shaped cells, many of which are muscular, and external to it is a zone of pulp tissue especially rich in lymphoid cells.

In *the Rat* the splenic follicles are remarkable in containing not only branching capillaries, but also, in many cases, branching arterioles. The intrafollicular capillary plexus is very distinct, both on account of the number of capillaries, and on account of the numerous endothelial nuclei in their walls that stain deeply with hæmatoxylin. The cells resemble those in the follicles of the rabbit. Around the follicle is a layer of muscle fibre cells, together with a few strands of connective tissue. There is an extrafollicular belt of lymphoid cells, such as are found associated in other spleens with the germinal centre. The intrafollicular reticulum is unusually conspicuous. It is composed of delicate branching filaments, with clear, faintly blue-stained oval cells at the nodal points. It seems to be continuous on the one hand with the wall of the artery, and on the other with that part at least of the limiting fibrous layer that is composed of connective tissue strands. It is distinctly denser and stronger towards the periphery of the follicle.

In the spleen of *the Guinea-pig* the greater part of the parenchyma is composed of

lymph follicular tissue, which exists in the form of a continuous adenoid sheath around the artery. The intrafollicular capillaries are much less evident than in the follicles of other Rodents. The arrangement of the cellular elements is similar. The peripheral fibrous layer contains little muscle, resembling in this particular the hilar sheath and the tunica propria.

In the spleen of *the Hedgehog* the follicles are few. The intrafollicular reticulum is very delicate, and the walls of the capillaries are very thin. The cells of many of the follicles show a germinal character near the middle of the follicle with the daughter cells outside. There is a well-marked limiting fibrous zone, composed principally of muscle, which is arranged in two or three layers. In this spleen the continuity of the peripheral muscular layer with the hilar sheath is very clearly seen. (Plate I. fig. 4.)

In the spleen of *the Child* the follicles are neither numerous nor sharply defined from the surrounding pulp. The special arterial branch is large in relation to the size of the follicle. Between its muscular coat and the lymphoid cells there is a somewhat thick layer of loose fibrous tissue, which contains a few elliptical nuclei. The follicular capillaries are neither conspicuous nor numerous; their walls are very delicate, and contain few nuclei. They are most numerous near the middle of the follicle, and are often surrounded by a fibrous sheath derived from that of the artery. The intrafollicular reticulum is very strongly developed, and its outer portion seems to consist of the separated fibres of the inner layer of the hilar sheath. The cellular elements of the follicle are of two kinds, lymphoid cells and large protoplasmic corpuscles. In many follicles the latter are grouped around the artery so as to form a core that is surrounded by lymphoid cells. Such a core may occupy about a fourth of the entire follicle. The cells that form it are round, oval, or polygonal in shape, and consist of a round nucleus staining faintly blue with hæmatoxylin, surrounded by coarsely granular protoplasm, staining deeply pink with eosine. Although these cells are found principally collected together in a central area, isolated examples also occur among the lymphoid cells at all distances from the centre, and even at the periphery of the follicle.

The cells vary much in size; the smaller are usually near the middle of the core, and these are much less deeply stained than the larger ones, both as regards their protoplasm and nucleus. The nuclei are sometimes large, round, and vesicular, sometimes horse-shoe shaped, and occasionally two, situated at a considerable distance from each other, are connected by a slender filament of nuclear substance. There is evidence of division by karyokinesis as well as by simple transverse fission. Sometimes a large cell may be seen to be filled with deeply stained nuclei, a mere rim of pink-stained protoplasm remaining. Many of the cells, and especially the larger ones, are vacuolated.

The origin of these cells can as yet only be conjectured. Frequently they appear to spring from the fibrous sheath of the artery and capillaries of the follicle. But such cells occur also in the arterial lumen, both intrafollicular, and while surrounded by the hilar sheath alone. Stilling * in 1886 described "bright centres" in the follicles of the

* Stilling (21), p. 18.

human spleen; he considers that they are pathological, and that they are composed of "epithelial elements." He found them only in emaciated individuals, and once in a case where death was registered as due to anæmia following hæmorrhage. They are, according to our own observation, constant in the child's spleen (the structure of which is always of necessity doubtfully normal), but we have found similar cells in the follicles of a strong adult dog (which was certainly ill nourished and probably also anæmic), in those of a healthy kitten, and in other healthy animals. It seems to us, therefore, that they are not necessarily pathological. Around the follicles there is a zone of fibrous tissue, consisting of two or three layers of nucleated fibres, derived from the hilar sheath.

In *the Human Fœtus* the cells of the follicles are large, and resemble the cells in the germinal centre of the lower mammals. Very rarely a cell may be seen resembling the protoplasmic corpuscles in the follicles of the child's spleen. The peripheral fibrous zone is more distinct than in the spleen of the child.

In *the Human Adult* the majority of the follicular cells consist of a small, round, deeply stained nucleus, surrounded by a rim of granular protoplasm staining pink with eosine. Some of the cells are like free nuclei, and a very small number are large and granular, like the protoplasmic cells in the follicles of the child's spleen. The intra-follicular reticulum is more strongly developed than in any other spleen.

Summary regarding the Splenic Follicles.

1. In the fish, amphibians, and reptiles the lymphoid cells form a continuous sheath, of even thickness, around the artery.

2. In mammals and in some birds the lymphoid cells accumulate in the form of nodular swellings—the splenic follicles—which occur at irregular intervals along the course of the arteries.

3. *The accumulation of lymphoid cells occurs between the hilar sheath and the artery.*

4. Large lymphoid cells (leucoblasts) occupy the middle of many of the follicles in the adult spleen (forming the germinal centre as described by FLEMMING in lymphatic glands), and by their division give rise to small uninucleated lymphoid cells (as pointed out by MÖBIUS *) which are extruded into the pulp. The small cells are produced both by direct division and by indirect karyokinesis.

5. *The intercellular substance of the follicles consists of two elements*, a delicate adenoid reticulum (MÜLLER †, W.) and a viscid albuminous substance (HUXLEY ‡).

6. *The follicles are surrounded, except where the artery enters and leaves, by a fibro-muscular covering, which is a remnant of the hilar sheath.*

This covering is not a separate membrane, as SANDERS § thought, neither is it a condensation of the pulp reticulum as stated by most observers and recently by BANNWARTH.‖

* MÖBIUS (19), p. 343. † W. MÜLLER (12), p. 355. ‡ HUXLEY (7), p. 81.
§ SANDERS (3), p. 82. ‖ BANNWARTH (26), pp. 379, 381.

Chapter III.

The Ellipsoidal Sheath of the Splenic Arteries and the Splenic Ellipsoids.

The smaller arteries in *the Kitten's* spleen, after leaving the follicles, divide dichotomously into several branches, each ending in a bulbous swelling, termed by W. Müller an ellipsoidal capillary sheath, or simply an ellipsoid. The thick-walled vessel passes for a short distance into the substance of the ellipsoid and is continued either as a single thin-walled vessel running in its long axis and leaving it undivided at the opposite pole, or more usually divided into several such vessels which leave at different points. Each emergent vessel opens into the blood-sinuses of the pulp. As the name implies, they are usually oval in shape; they are sometimes nearly round, and sometimes pyriform. Each is composed of several rings of nucleated spindle cells, which are probably muscular, arranged concentrically around the axial vessel or vessels, and imbedded in a granular ground substance. In addition to the rings of spindle cells, which are more strongly developed near the periphery of the ellipsoid, there are scattered at irregular intervals throughout its substance a few lymphoid cells. At the margin of each there is a layer of spindle-shaped cells, and the whole is suspended in a blood-sinus by the vessels that enter and leave.

In the spleen of *the Skate* the smallest arterial branches are enveloped in a somewhat thick fibrous sheath, but this does not show any localised swelling. In the spleen of the cat-fish, Pouchet * has described cylindrical bodies, circularly striated and containing nuclei, which apparently resemble those described in the spleen of the kitten.

In the spleen of *the Cod*, after the arteries have become much reduced in size and separated from the veins, they are surrounded by a continuous sheath of almost structureless tissue, which, varying in thickness, has an undulating surface and is oval in section. To distinguish it from the circumscribed ellipsoids it may be termed the ellipsoidal sheath. Imbedded in it are a few large clear cells arranged concentrically, and also here and there smaller lymphoid cells that stain more deeply with hæmatoxylin. The ellipsoidal sheath has apparently no limiting membrane, but there is a peripheral blood-sinus in which, together with red blood-corpuscles, are numerous deeply stained lymphoid cells, which are mostly crowded at the edge of the ellipsoidal sheath, and resemble the smaller cells contained in it, and also those forming the adenoid sheath. Separating adjacent blood-sinuses are trabeculæ-like strands of fibrous tissue containing two or three layers of spindle cells, which strands are apparently the remnant of the hilar sheath. A reticulum of fine fibres may sometimes be seen to stretch between these strands and the opposite surface of the ellipsoidal sheath.

In the spleen of *the Frog* there does not appear to be any ellipsoidal sheath like

* Pouchet (18), p. 501.

that in the cod, but only a somewhat thick fibrous sheath around the smaller arteries as in the skate.

In the spleen of *the Tortoise*, after the lymphoid sheath of the artery ceases, its fibrous sheath (tunica adventitia) becomes thicker; the axial vessel becomes smaller, and shortly divides into two or more branches which ultimately open as thin-walled vessels into the venous sinuses of the pulp. The tissue forming the substance of the sheath is so finely fibrillated as to be almost granular. It contains a few large, vesicular lymphoid cells like those of the tunica propria and hilar sheath, which appear to multiply, sometimes, if not always, by transverse fission. The outline of the sheath is irregular, and in some places there is the appearance of a delicate structureless limiting membrane. There is often the appearance of a venous sinus around the sheath, but sometimes its outer wall seems to be connected with a fine reticulum.

In the spleen of *the Grass Snake* there does not seem to be any structure homologous with the ellipsoidal sheath.

In *the Hawk*, as the muscular coat of the splenic artery grows thinner the fibrous coat becomes thicker, until it forms a sponge-like investment containing lymphoid cells. The muscle fibre cells derived from the hilar sheath seem to form a limiting layer for the ellipsoidal sheath. It is composed of a strong fibrous network, that stretches between the peripheral muscular layer and the vessel wall, in the meshes of which are a few clear, faintly stained lymphoid cells. It is suspended in a capacious venous sinus, within which the cellular elements of the pulp are found, and across which the fine fibres of a delicate reticulum are sometimes seen to stretch.

The spleen of *the Rook* contains numerous circumscribed ellipsoids, which resemble in general characters those found in the spleen of the kitten. Into each ellipsoid an arteriole enters, and from each, at one or more points, a thin-walled vessel leaves, while from the axial vessel capillaries destitute of endothelium radiate outwards to the surface. The afferent is distinguished from the emergent vessel by the character of its endothelial lining; in the former this is composed of spindle-shaped cells occurring at considerable intervals, in the latter of rounded cells placed near together. The endothelium changes in character almost immediately after the entrance of the arteriole, and it again becomes flattened shortly after the vessel has left the ellipsoid.

In shape the ellipsoids are usually oval, but sometimes trifoliate. Their substance consists of cells, spindle-shaped or round, imbedded in a structureless ground substance. The round cells are either small lymphoid cells like free nuclei, that stain deep blue with hæmatoxylin, or protoplasmic cells, twice, thrice, or four times the size of the former, consisting of a small, round nucleus surrounded by granular protoplasm, and resembling the cells in the follicles. The spindle cells are concentrically arranged around the axial vessel. Running between the round cells, in addition to the capillaries, are highly refractile lines which look like strands of elastic tissue.

In almost every instance there are indications of an investing membrane of spindle-shaped cells, apparently muscular in nature. This enveloping layer is evidently a

vestige of the hilar sheath ; longitudinal fibres are seen to be continuous between the two, and also between both and the peripheral layer of the follicles. The ellipsoids are usually seen to be surrounded by a clear space, probably a venous sinus, but this has not a distinct outer wall.

In the spleen of *the Pigeon*, around the terminal portion of the arteries, there is a short length of ellipsoidal sheath, similar to the extended sheath in the spleen of the hawk. It consists of a granular undifferentiated matrix, in which are imbedded a few clear faintly stained nuclei, but no concentric spindle cells. There is a clear space surrounding it, across which the strands of a delicate reticulum stretch, as in the spleen of the hawk ; and there are considerable numbers of lymphoid cells grouped around the sheath, as in the spleen of the tortoise. But there does not appear to be any definite layer at the periphery of the sheath, nor any separating the venous sinus from the pulp. Thus the ellipsoidal sheath in the spleen of the pigeon seems to afford a connecting link between the extended ellipsoidal sheath in the spleens of the hawk, tortoise, and cod, and the circumscribed ellipsoid in the spleen of the rook, and in the spleen of many mammals.

In the spleen of *the Ox*, as in the spleen of the pigeon, the arterial terminations are surrounded by short lengths of an ellipsoidal sheath. There is a comparatively clear area surrounding each stretch of ellipsoidal sheath, from which the microscopic trabeculæ of the pulp are absent, and in which run numerous anastomosing venous sinuses. (Plate II. fig. 5.) As compared with the ellipsoids of some other ungulate animals, its most striking feature is its length : it is seven or eight times as long as it is broad. In outline it is irregularly undulating, and may be compared to a much gnarled club. An arteriole, having lost its muscular coat, runs in a wavy manner through the long axis of the expansion, but it does not apparently give off any capillaries, nor does it divide, but opens as a thin-walled vessel into the venous sinuses of the surrounding clear area. The substance of the sheath consists of a granular ground substance that stains deeply pink with eosine, in which are imbedded large, round or oval cells having a well marked intranuclear network. These vary in size and also in depth of staining with hæmatoxylin, and, while most are lymphoid cells resembling free nuclei, others have a rim of hyaline protoplasm that stains deeply pink with eosine. Similar cells are sometimes seen lying free near the sheath. There are occasionally large vacuoles in the granular matrix. At the periphery of the sheath is a membrane containing spindle-shaped nuclei, and surrounding that is a venous sinus which apparently communicates with the sinuses of the clear area.

In the spleen of *the Sheep* there are numerous ellipsoids, which are sometimes lobed, but are usually in the form of a long oval. The axial vessel retains its muscular coat for a short distance, and frequently divides into two or three thin-walled vessels before leaving the ellipsoid to open into the venous sinuses of the pulp. Breaks in the continuity of the wall of the axial vessels are frequently seen, but no distinct capillaries were observed. The substance of the ellipsoid consists of a fibrous network, at the nodes of which are faintly stained cells like connective tissue corpuscles. The meshes some-

times contain red blood-corpuscles, suggesting that the apertures in the wall of the axial vessel may lead directly into the spaces of the network. There are, in addition to the network, a few spindle cells arranged concentrically around the axial vessel. There is a well marked limiting membrane, which is sometimes seen to be composed of unstriped muscle. In most cases the ellipsoid is seen to be surrounded by a venous sinus.

In the spleen of *the Pig* the ellipsoids resemble closely those in the sheep, but the fibrous reticulum and the limiting layer are not so strongly developed. In their substance are concentrically arranged spindle cells, lymphoid cells, and protoplasmic corpuscles. There is an appearance of circular muscular fibres in the wall of the axial vessel, more delicate and wider apart than those in the arterioles. A wide venous sinus surrounds the ellipsoid and communicates with the veins of the pulp.

In the spleen of *the Dog* the ellipsoids are round or oval in transverse section; but in longitudinal section their outline is irregular, being prolonged into angles at the places of emergence of the vessels, so that their shape is sometimes like that of a multipolar nerve cell. (Plate II. fig. 6.) A somewhat large arteriole enters the ellipsoid, and divides into two or three branches which leave it at different points. As in the ellipsoids of the pig, the axial vessel appears to possess a thin circular muscular coat. From the sides of the axial vessels spring numerous delicate, wavy, capillary vessels, destitute of endothelium, which anastomose to form a plexus and open into the peripheral blood-sinus. In transverse section the lumen of the capillaries sometimes seems to be of considerable size, quite large enough to transmit a red blood-corpuscle.

The substance of the ellipsoid consists of a fibrous reticulum with connective tissue corpuscles at its nodes, and lymphoid cells in its meshes, together with a small amount of granular matrix. The reticulum is like that in the ellipsoid of the sheep, but is not so strong and has smaller meshes. Appearing to form a part of the reticulum are a few spindle cells arranged concentrically around the axial vessel. There is a limiting layer formed of a somewhat strong membrane and spindle-shaped cells, or nuclei. Surrounding each ellipsoid is a capacious venous sinus, that contains cells similar to the cellular elements of the pulp and red blood-corpuscles. The peripheral sinuses communicate with each other by thin-walled channels, and similarly with the venous sinuses of the pulp, and with the small veins that are laterally attached to the trabeculæ. One cannot help being struck with the number of points of resemblance between the ellipsoids and the follicles—the axial vessel, the radiating capillaries that anastomose, the peripheral layer sometimes muscular, the fibrous reticulum, the lymphoid cells—but in each of these particulars there is difference as well as resemblance.

In the ellipsoids of the spleen of *the Cat* the arrangement of vessels is similar to that in the dog, as also is their substance, except that it is a little denser. There is a distinct limiting layer of spindle-shaped cells, but the peripheral blood sinus is not always distinct in the adult cat (although it nearly always is in the kitten); it is indeed sometimes nearly obliterated in the adult, apparently from compression by the surrounding pulp.

In the spleen of *the Porpoise* there does not seem to be anything corresponding to the ellipsoids, and in the *Narwhal* the terminal arteries are merely invested by a somewhat thick fibrous sheath that contains a few lymphoid cells.

In the spleen of *the Rabbit* the arteries, after leaving the follicles, are invested by a continuous fibro-cellular "ellipsoidal sheath." The fibres are usually spindle-shaped, and are arranged both longitudinally and concentrically. Within long meshes formed by them, lymphoid cells are found. There is an indistinct blood-sinus at the periphery of the sheath, something like that in the tortoise and rook. In *the Rat* and *Mouse* there is a similar ellipsoidal sheath, which is, however, surrounded by a well-marked blood-sinus. In *the Guinea-pig* a similar sheath forms septa between some of the large sinuses of the pulp.

In *the Hedgehog* the ellipsoids are numerous and conspicuous. In transverse section they are round; in longitudinal section they are seen to be oval, or not unfrequently trilobed. The vessels are arranged as in the dog and cat. The axial vessel has a distinct circular coat consisting apparently of delicate muscle fibres placed at long but regular intervals from each other. The substance of the ellipsoids consists of a considerable amount of a granular ground substance, in which are imbedded numerous clear, uninucleated lymphoid cells, and of an ill-developed fibrous reticulum that contains many concentrically arranged spindle cells, which are in all probability muscular. There is a well-developed external layer composed of strong fibres having long nuclei, which are almost certainly muscular. Surrounding the ellipsoid is a somewhat narrow venous sinus.

In *the Human Spleen* after the arteries leave the follicles they are continuously invested by a fibro-cellular ellipsoidal sheath as in the spleen of the Rodents. It is composed of a network of strong connective tissue strands which, near the periphery, is denser and composed of fibres arranged mainly longitudinally, and in the meshes of this network are some lymphoid cells. At first the sheath is about twice the thickness of the diameter of the vessel, but as the artery becomes smaller, the sheath becomes thinner; the lymphoid cells decrease in number until they practically disappear, while the fibres persist so as to form a longitudinal sheath until the vessel opens into the spaces of the pulp.

Commentary.

The ellipsoids were first noticed by BILLROTH * in the spleen of the bird, and have since been described by SCHWEIGGER-SEIDEL,† under the name of the capillary sheath, in the pig, dog, and cat, later in the same animals by W. MÜLLER ‡ and KYBER,§ and still later by POUCHET ‖ in the Selachian cartilaginous fish. Since the preceding observations were made they have been described by Dr BANNWARTH ¶ in the spleen of the cat, and, as we can testify, with fulness and accuracy. He has, however, failed

* BILLROTH (8), p. 97. † SCHWEIGGER-SEIDEL (10), p. 465. ‡ W. MÜLLER (12), p. 360.
§ KYBER (13), p. 561. ‖ POUCHET (18), p. 498. ¶ BANNWARTH (26), p. 398.

to notice the peripheral blood-sinus, and consequently, as we think, falls into error of observation in some correlated points. He states,* for example, that the network of the ellipsoids is continuous with that of the pulp, while, as a matter of fact, the two are separated by a blood-sinus and a special envelope. He notices† the fine canals unlined by endothelium in the substance of the ellipsoid, but thinks that they all terminate in the meshes of the reticulum, while we believe that most of them, if not all, after anastomosing with each other, open into the peripheral blood-sinus. He is able to state positively‡ that the concentrically arranged nuclei are those of muscle fibres. To KYBER§ belongs the credit of observing the presence of blood-channels at the periphery of the ellipsoids; he, however, did not recognise that they were cavities or sinuses, but looked upon them as capillary veins. KLEIN,‖ differing from all authors, considers that the axial vessel of the ellipsoid is not a capillary but a minute artery, and as regards several animals we are able to confirm his observation. W. MÜLLER¶ describes the termination of a nerve fibre in an ellipsoid, but this single observation has never been confirmed.

Many different views as to the significance of the ellipsoids have been advanced; BILLROTH** thinks they correspond with the adenoid sheath of the Amphibia; SCHWEIGGER-SEIDEL†† that they serve to filter the blood; KYBER‡‡ that they are merely local swellings of the arterial sheath; and BANNWARTH§§ looks upon them as foci for the transformation of the tissue of the arterial sheath into pulp tissue, and that they serve to narrow the blood stream. We can agree in some measure with all of these views, except the former part of the last, for we think that they are the representative of the adenoid sheath, and they are swellings of the tissue of the arterial sheath, and also that they may filter the blood by allowing the blood plasma to escape through the minute capillary channels into the peripheral sinus while the corpuscular elements of the blood are retained in the axial vessel. But we also think that they may be relics of the continuous ellipsoidal sheath of the lower vertebrates, and would suggest that they may subserve the function both of contractile bodies on the course of the main vessel, and of expansile bodies within capacious blood chambers; that they may serve to minimise the effect of the pulse wave, transmitting the blood more gradually from the relatively very large arteries to the thin-walled blood spaces of the pulp, to empty at the same time by their expansion the peripheral blood-sinus, and by their contraction to help the flow of blood through the emergent veins.

Summary regarding the Ellipsoidal Sheath and the Splenic Ellipsoids.

1. The terminal portion of the splenic arteries in the Teleostean fish, in the tortoise, and in the hawk is invested by a continuous ellipsoidal sheath, which consists of a homogeneous ground substance containing a few lymphoid cells.

* BANNWARTH (26), p. 403. † BANNWARTH (26), p. 415. ‡ BANNWARTH (26), p. 404. § KYBER (13), p. 562.
‖ KLEIN (17), p. 426. ¶ W. MÜLLER (12), p. 360. ** BILLROTH (8), p. 97.
†† SCHWEIGGER-SEIDEL (10), p. 971. ‡‡ KYBER (13), p. 562. §§ BANNWARTH (26), p. 431.

2. *In the Mammals it is invested either*, as also in the rook, *by a circumscribed swelling of an ellipsoidal sheath—an ellipsoid, or by a continuous stretch of an ellipsoidal sheath*, both containing a few lymphoid cells and some concentrically arranged spindle cells (that are probably, sometimes at least, muscular) imbedded in a homogeneous ground substance, while the former possesses a fibrous network, and the latter longitudinally arranged fibres in addition.

3. *The sheath is surrounded by a venous sinus which separates it from the pulp, and which has distinct walls in those Mammals alone that have circumscribed ellipsoids.*

4. The ellipsoids have a special nucleated covering, *which in some instances is muscular.*

5. The axial vessel of the ellipsoid has, at least sometimes, a circular muscular coat.

6. The axial vessels, in many animals, give off capillary channels which have no endothelial lining, and *which anastomose before opening ultimately into the blood-sinus that surrounds the ellipsoid.*

7. The axial vessels end by leaving the ellipsoid as thin-walled veins which open into the spaces of the pulp.

8. *The peripheral blood-sinus of the ellipsoid communicates directly with adjacent ellipsoidal sinuses and splenic veins, but not with the emergent vessel of another ellipsoid.*

9. *The ellipsoid is associated with greater muscularity of the supporting framework of the spleen than the ellipsoidal sheath.*

Chapter IV.

The Splenic Pulp.

In the spleen of *the Dog* the pulp consists of a reticulum formed by the anastomosing processes of branching cells, the meshes of which contain several kinds of free cellular elements.

The supporting cells of the pulp consist of a cell plate, from which numerous radiating plate-like processes pass, and in the middle of which is a round or oval nucleus. The cell plate and processes are transparent, homogeneous or slightly granular, and stain faintly pink with eosine. When the plate-like processes are cut longitudinally they appear as long thin fibres. (Plate II. fig. 7.) The reticulum seems to be sometimes directly continuous with the terminations of the smallest trabeculæ, also with the under surface of the capsule, with the sides of the larger trabeculæ and of the hilar sheath, and with the walls of the venous sinuses. But it apparently is not connected with the reticulum of the follicles, and differs from it in nature, inasmuch as the latter seems to

consist, like the reticulum of a lymph gland, of a network of fibres with cells superimposed at the nodes.

The corpuscular elements of the pulp are mainly of four kinds:—(1) Round or oval lymphoid cells, measuring 3–7 μ. in diameter, which stain deeply with hæmatoxylin, and resemble the cells forming the outer zone of the follicles. They have only a very small amount of peripheral protoplasm, if any. (2) Protoplasmic corpuscles of oval shape, consisting of a round or oval nucleus surrounded by a considerable amount of pink-stained protoplasm,* and measuring 7–10 μ. in diameter. (3) Cells containing pigment resembling in size and shape the protoplasmic corpuscles. (4) Giant cells, consisting of coarsely granular protoplasm which stains deeply pink with eosine, and in which are imbedded several nuclei. The usual shape of these cells is lobed oval, and their average measurement is about 30 μ long by 15 μ broad.

In *the Skate* the reticulum of the splenic pulp is composed of a branching system of expanded fibres which stain faintly with eosine, and which are connected with narrower, stronger, more deeply stained fibres. The expanded fibres are sections of the plate-like processes of branching nucleated cells. The narrower stronger fibres seem to be the walls of the venous radicles; they are frequently crescentic in shape, and have on their inner concave surface a layer of endothelial cells.

The cells of the pulp are of four principal kinds:—(1) The most numerous are clear, round cells like free nuclei. They stain faintly with hæmatoxylin, the chromatin particles being arranged in a ring near the periphery of the cell. Their average size is about 8 μ. (2) Less numerous cells consisting of granular protoplasm that stains pink with eosine, surrounding a round, oval or horse-shoe shaped nucleus. These cells resemble some of the cells contained in the representatives of the follicles. (3) Cells like the protoplasmic corpuscles, but containing pigment granules of different sizes. These resemble the majority of the cells of the follicles. (4) Cells similar in size and shape to the third variety, but vacuolated, the vacuoles containing rounded particles of pigmented protoplasm which have no nuclei and are about a fourth of the size of the coloured blood-corpuscles.

In *the Cod and Ling* the reticulum of the splenic pulp consists of anastomosing plate-like processes of nucleated cells as in the skate, but the meshes are apparently wider. The cells of the cod's spleen are mainly of three kinds:—(1) Round lymphoid cells of different sizes, sometimes possessing a narrow rim of protoplasm, but usually like free nuclei. (2) Protoplasmic corpuscles varying in size from about a half to a little more than the size of their average red blood-corpuscle. Both protoplasm and nucleus stain with hæmatoxylin, the former faintly, the latter somewhat deeply. The larger have the size and shape of the coloured blood-corpuscles. (3) Cells containing pigment occur here and there in clumps.

* Whenever the phrases "pink-stained protoplasm" and "blue-stained nuclei" occur in the text they mean respectively "protoplasm that has been stained pink with eosine" and "nuclei that have been stained blue with hæmatoxylin."

In the spleen of *the Frog* the reticulum of the pulp consists of large branching cells, the plate-like processes of which do not taper so much before joining with others as in the spleen of the fish. The processes are so much expanded that sometimes the sectional area seems to be chiefly occupied by them, the meshes appearing as comparatively small fenestræ in a nucleated membrane. When the processes are seen in oblique section or in profile, they appear like narrow bands in the one case or somewhat fine threads in the other. (Plate II. fig. 8.) Each cell contains usually one large, oval, slightly granular, faintly blue-stained nucleus, but there are sometimes two, three or four. The meshes of the reticulum vary much in size and shape. The processes of the cells of the reticulum appear to be continuous with the walls of the venous sinuses, and to join the outer wall of the artery.

The cells of the pulp are mainly of five kinds in addition to the red blood-corpuscles: —(1) Round lymphoid cells resembling free nuclei are far the most abundant. They vary in size from a half to four or five times the size of the nucleus of a red blood-corpuscle. (2) Round protoplasmic corpuscles apparently identical with the small leucocytes. Their size is a little more than half that of the red blood-corpuscles, and they are composed of finely granular protoplasm, staining faintly pink with eosine, in which is imbedded sometimes a single small round nucleus that stains somewhat deeply blue with hæmatoxylin; but more usually there are two or three such in a single cell. (3) Large protoplasmic corpuscles about twice the size of a red blood-corpuscle, which seem to be identical with the large leucocytes. They are best seen in the intracapsular venous sinuses, but are far more numerous in the parenchyma immediately underneath the capsule. They consist of somewhat finely granular protoplasm, that stains faintly blue with hæmatoxylin, and from three to eight faintly stained nuclei. They sometimes show very large karyokinetic figures. (4) Round or oval cells, found especially near the middle of the pulp, about the size of the small leucocyte, whose protoplasm is in the form of round coarse granules, which stain very deeply pink with eosine, each having a single, oval, blue-stained nucleus. These probably correspond with the eosinophilous cells of Waldeyer. (5) Cells containing pigment are especially numerous in the outer zone of the parenchyma and particularly in the winter frog. In shape they are round or oval, and are similar in size to the large leucocytes. They have a single nucleus usually, but sometimes they are multinucleated. The smaller consist of granular, faintly blue-stained protoplasm, in which are scattered numerous dark brown granules. The larger appear to consist almost entirely of pigment particles, the nucleus being pushed to the periphery of the cell. The cells appear sometimes to be vacuolated. In very thin sections, some of the larger pigment masses are seen to be composed of oval parcels of pigment granules, each parcel being about the size of a red blood-corpuscle, and containing a faintly blue-stained nucleus near its margin. This appearance suggests that each oval parcel may be a degenerated red blood-corpuscle. The pigment does not blacken with ammonium sulphide.

Within the intracapsular venous sinuses of the winter frog, and in the summer frog,

more especially in the pulp immediately under the capsule, the red blood-corpuscles may be seen in various stages of transformation. In some the perinuclear protoplasm shows here and there faintly blue-stained areas; in others the whole of the protoplasm is slightly blue-stained; in other cells the blue staining of the protoplasm is almost as deep as that of the nucleus, and in others the nucleus cannot be distinguished. The protoplasm breaks up into round, blue-stained, coarse granules, which at first appear to be imbedded in a blue-stained homogeneous matrix, but are subsequently apparently free within a cell capsule, when the position of the nucleus is indicated by an oval shaded area near one pole of the cell. Ultimately the granules escape from the cell capsules, and collect into large irregular masses that adhere to the walls of the venous sinuses, or pass down by the venous channels into the parenchyma towards the larger veins near the middle of the spleen.

In the spleen of *the Tortoise* the reticulum of the pulp closely resembles that of the frog's spleen. The cells that form it are, however, smaller and more delicate, and they have more processes. The meshes are usually oval or round, but near the walls of the veins, where the cell processes are thread-like, they are angular. The supporting cells are continuous with the trabecular sheath of the veins, and with the inner muscular layer of the capsule. The reticulum of the periarterial adenoid tissue seems to be continuous with that of the pulp, but the former is altogether finer, the cell processes are thread-like, and they stain more faintly with eosine.

There are at least six different kinds of cells in the pulp; these are:—(1) Lymphoid cells, similar to those of the adenoid sheath but slightly larger, without peripheral protoplasm, and like free nuclei. (2) Protoplasmic corpuscles of round or oval shape, which vary considerably in size but are usually four or five times larger than a lymphoid cell. Each has usually a single nucleus, which is round, and at least half the size of the whole cell. The protoplasm is finely granular, and stains deeply pink with eosine. Similar cells, but smaller and staining more deeply with eosine, occur in clumps here and there throughout the pulp. (3) There are a few eosinophilous cells, which are more numerous just under the capsule than elsewhere. (4) Scattered in large numbers throughout the pulp are very small cells, oval, or nearly round, each having a single, round, deeply stained nucleus. The whole cell is about a half and the nucleus about a fourth of the size of a lymphoid cell. The rim of perinuclear protoplasm is hyaline and stains but slightly with eosine. The nucleus is almost vitreous in appearance, and has no nucleolus. (5) There is a small proportion of cells that contain pigment, which are about ten times larger than the lymphoid cells. Each has a single nucleus, little if any protoplasm, and is filled with golden yellow granules. Sometimes a cell may be seen having not only pigment granules but also granules that stain very deeply with eosine like those of the eosinophilous cells. (6) Giant cells occur in considerable numbers. They vary much in size, from about 16 to 22 μ in diameter. They consist of granular protoplasm that stains not very deeply with eosine, in which is imbedded one large round nucleus, and often in addition several small nuclei that resemble lymphoid cells in size and shape, and

generally stain more deeply with hæmatoxylin than the large nucleus. The protoplasm is frequently vacuolated, the vacuoles being usually about a fourth of the size of a red blood-corpuscle. Occasionally there is an appearance of a particle of protoplasm lying free in a vacuole. In shape the cells are usually oval but frequently irregular and sometimes almost spinous. Their general appearances are much like those of the giant cells found in the dog's spleen. (Plate II. fig. 9.) Within the intracapsular venous sinuses, as in the frog's spleen, are granular bodies that are evidently breaking down coloured blood-corpuscles.

In the spleen of *the Grass Snake* there is no true pulp. It is probably represented by the opened out fibrous tissue of the supporting framework, that contains numerous protoplasmic corpuscles, some lymphoid cells, and a few pigment-holding cells. The only reticulum present is that of the adenoid tissue.

The spleen of *the Hawk* resembles in many particulars the spleen of the bony fish; in both, the pulp is rudimentary, and the greater part of the parenchyma consists of the ellipsoidal sheath. There are, however, areas of parenchyma around the veins that appear to represent the pulp. There is in them a feebly developed reticulum consisting of nucleated cells with thread-like processes, in the meshes of which are a large number of protoplasmic corpuscles, a few characteristic lymphoid cells, and very numerous red blood-corpuscles.

In the spleen of *the Pigeon* the reticulum of the pulp is much more delicate than that of either the frog or tortoise; the cells forming it are smaller, the cell plate extends only a little way beyond the nucleus, and the cell processes are longer, more slender, and more numerous. Its meshes are usually oval and comparatively large, but sometimes they are smaller and nearly round.

The cells of the pulp are in the young pigeon apparently all small lymphoid cells, but in the adult there are in addition a few protoplasmic corpuscles, like the larger cells of the follicles, and a small number of pigment-holding cells. As in the spleen of the tortoise, some of the protoplasmic corpuscles occur in clumps; they stain more deeply with eosine, and are contained in the meshes of a somewhat stronger reticulum.

In the spleen of *the Rook* nearly all the cells of the pulp are large protoplasmic corpuscles like those in the follicles.

In the spleen of *the Pig* the reticulum of the pulp consists of nucleated cells that give off processes, which are usually broad and plate-like, but sometimes narrow and fibre-like. In a cell with broad processes they are few in number and comparatively short, and in cells with slender processes the converse as a rule holds true; the processes in the former case by their anastomosis form nearly round meshes, in the latter case elongated elliptical meshes.

The reticulum appears to be directly continuous with the numerous microscopic trabeculæ of the pulp, the two blending without any appreciable line of junction. Often nearly parallel longitudinal ridges pass from a trabecula into an expanded portion of the reticulum, and these seem to be continuous with its muscular fibres.

In the pulp of the adult spleen there are four kinds of cells:—(1) Lymphoid cells, which measure from 4–5 μ, stain deeply with hæmatoxylin, and resemble the cells of the outer zone of the follicles. (2) Protoplasmic corpuscles, measuring 6–8 μ with usually a single, round, deeply stained nucleus, which is surrounded by a narrow or broad rim of hyaline protoplasm. (3) Coarsely granular or eosinophilous cells occur in small numbers, and vary in size correspondingly with the protoplasmic corpuscles. The largest are oval, and their very coarse granules obscure the nucleus if such is present. (4) Pigment-holding cells are in some spleens exceedingly numerous, in others quite sparse. They are usually oval in shape and measure from about 15 μ to 20 μ longitudinally by about 12 μ in breadth. The pigment grains are of a yellow colour, and are of irregular size and shape; they are surrounded by a cell wall, but there is apparently no protoplasm between them. An oval, blue-stained nucleus is sometimes to be seen about the middle of the cell. The cells tend to adhere firmly to the reticulum.

In the splenic pulp of *the Young Pig*, aged three months, similar cellular elements are to be found, except pigment-holding cells, and there are in addition giant cells. (Plate II. figs. 10 and 11.)

The giant cells vary considerably in size, but their average measurement is about 30 μ in length and 18 μ in breadth. They are not by any means numerous: on an average about sixty are present in each section.* Their characteristic shape is oval. Their substance is a coarsely granular protoplasm, which stains of a deep pink colour with eosine, and which in the unstained condition is of a yellow colour. They have usually several nuclei, oval or round in shape, which are frequently connected together by threads of nuclear substance, but more often they appear to be isolated. Some of the smaller giant cells have only one large nucleus. The isolated nuclei of the multinucleated forms are sometimes near the middle of the cell, but usually near its periphery; their average size is 5–8 μ. Near the margin of many of the giant cells are rounded vacuoles, in size a little larger than the nuclei; in some that are situated quite close to the periphery of the cell there may be seen a deeply stained nucleus. Sometimes there is a mouth-like opening at the margin of the cell, which is probably the result of the rupture of a vacuole, and occasionally a vacuole is seen to be connected with the surface by a somewhat narrow channel, thus forming a pyriform space.

Clustered near the margin of the giant cells, usually at points corresponding with the mouth-like openings, are cells that have the character of erythroblasts. Their usual measurement is 9–10 μ in diameter. They are round or oval in shape, and consist of a deeply blue-stained, round nucleus, that has a well-marked intranuclear network, but no nucleolus, which is surrounded by a rim of hyaline protoplasm, which stains deeply with eosine, and is of a yellow colour when unstained. The nuclei are

* By the term "section" in this relation is meant a section through the entire spleen at its thickest part in its transverse axis. In giving the number of giant cells in a section in the different spleens, my aim is to afford a basis for a rough comparison between the spleens. Each section contains only a portion of each of the giant cells enumerated.

a little larger than the isolated nuclei of the giant cells; they measure 7–8 μ in diameter, and they stain somewhat less deeply with hæmatoxylin. They have sometimes a rather wide rim of protoplasm and sometimes two nuclei, while some of the cells lying near the open mouths of vacuoles appear not to have any perinuclear protoplasm. Cells similar to these occur in clumps at frequent intervals throughout the pulp.

In two spleens of *fœtal* pigs similar giant cells were found, but in them the vacuolation is not so pronounced, and there is less isolation of their nuclei. The latter are sometimes in the form of a convoluted chain, and occasionally numerous pyriform nuclei radiate outwards from the middle of the cell, their apices pointing inwards. The giant cells in the fœtal spleen are slightly less numerous than in the spleen of the young pig, and they are also a little larger, their average measurement being 30 μ by 22 μ, as compared with 30 μ by 18 μ.

In the adult *Ox* and *Sheep* the splenic pulp very closely resembles that in the adult pig, so that one description may serve for the three ungulate animals.

In the spleen of *the Dog* the cell processes that form the reticulum are much less expanded than those in the pig, and the whole reticulum is more delicate.

Giant cells were present in the spleens of five dogs that were examined. In the spleens of three adult dogs they were comparatively few in number, about fifteen in each section; in the spleen of a half-grown dog they were more numerous, about fifty in a section; and in the spleen of a puppy they occurred in large numbers, on a rough estimate, about a thousand in each section.

In the spleen of *the adult Dog* they were mainly situated in the neighbourhood of the follicles. In one spleen a comparatively small giant cell with four or five nuclei was separated from the artery of the follicle merely by two rows of lymphoid cells, and a similar giant cell, with eight or nine nuclei, was placed just outside the same follicle. In another adult spleen giant cells occur in groups about the middle of the follicles, and others are in the pulp immediately surrounding them. At the periphery of one follicle there was found a giant cell only partly in the pulp: it measured 28 μ by 16 μ. In another follicle there were seen six or seven somewhat large giant cells, the largest of which (measuring 30 μ by 14 μ) had a single, large, round nucleus (about 13 μ in diameter), while in the adjoining pulp there was a multinucleated giant cell, and in a neighbouring venous sinus a mass of protoplasm similar to that of the giant cell, but apparently non-nucleated. This spleen was obtained from an ill-nourished and probably slightly anæmic dog.

In the spleen of *the half-grown Dog* some of the giant cells had vacuoles in their substance and also mouth-like openings on their surface. The nuclei of the giant cells showed great diversity of arrangement. Frequently seven or eight faintly stained nuclei were packed together near the middle of the cell in the form of a sphere. Sometimes a cell had three or four large, round nuclei, the cell protoplasm showing indication of division corresponding with each nucleus. The most common appearance was a number of oval nuclei arranged near the middle of the cell close to, but not

touching, each other. Occasionally the nuclei have the shape of grains of corn. Near a giant cell that was apparently breaking up, a nucleus, unsurrounded by hyaline protoplasm, was seen to be connected by a thread of chromatin with the nuclei of the giant cell, which was still surrounded by granular protoplasm. A noticeable feature of this spleen was the large amount of pink-stained granular material present in the larger veins.

In the spleen of *the Puppy* the cells of the pulp were mainly of three kinds:—(1) Round, small, deeply stained cells, measuring 4 μ in diameter, which in the pulp have a very faint rim of perinuclear protoplasm, and in the veins have a distinct rim. (2) Round or oval protoplasmic corpuscles, the erythroblasts, occur in numbers throughout the pulp and in the veins. Their hyaline protoplasm stains deeply pink with eosine, and their nucleus has no nucleolus, but an open intranuclear network. The diameter of the cell varies from 7–10 μ, that of the nucleus from 6–8 μ. (Plate II. fig. 12.) (3) The giant cells resemble closely those described in the spleen of the young pig; they show similar vacuoles and mouth-like openings. A vacuole usually contains either a small deeply stained cell like the homogeneous connected nuclei of the giant cells, or a protoplasmic corpuscle consisting of a large, clear, faintly stained nucleus, with characteristic intranuclear network, surrounded by a rim of hyaline or very finely granular protoplasm. The average measurement of the giant cells was about 36 by 28 μ. Their main substance consists of coarsely granular protoplasm which stained deeply pink with eosine, but at the periphery of the cell there was a zone of hyaline protoplasm which varies in breadth from a sixth to a third of its radius. Sometimes these two kinds of protoplasm are apparently separated by a narrow circular cleft, and often the hyaline rim seems to have separated like a rind from the granular core. The protoplasm of the giant cells, and also of the protoplasmic corpuscles, has a distinctly yellow colour in the unstained condition, similar to, but fainter than, that of the red blood-corpuscles, and both stain deeply with eosine.

Most of the small, deeply stained, apparently homogeneous nuclei, when near the centre of the cell, are connected by chromatin threads, but other nuclei, always isolated and usually near the periphery of the cell, are faintly stained, vesicular, and have a conspicuous intranuclear network. Similar nuclei are sometimes seen in buds or large bulgings of the giant cell, and occasionally such a nucleus, surrounded by a rim of protoplasm, is contained, apparently within a vacuole, in the substance of the cell, and seems to be of the same kind as erythroblasts surrounding the giant cell. (Plate II. fig. 12.) Sometimes all the nuclei are faintly stained and vesicular, then they appear to be unconnected with each other and nearly fill the cell. The giant cells sometimes show indications of division by multiple karyokinesis. They are sometimes to be found within the larger veins in the substance of the spleen.

In the spleen of *the Cat* the reticulum of the pulp closely resembles that in the dog's spleen, but the meshes seem to be slightly smaller and the cell processes somewhat

plate-like. The cellular elements of the pulp in *the adult spleen* are mainly lymphoid cells, small and uninucleated, like those of the outer zone of the follicles; but a few are larger and resemble the cells of the germinal centre. Protoplasmic corpuscles are comparatively few in number. Several spleens of adult cats were examined, and in only one of them giant cells were found, and in it there were not more than four in a section. Their nuclei were nearly always clustered in a ball near the middle of the cell, round which was found a comparatively narrow band of granular protoplasm that had a distinctly yellow hue when the section was stained with hæmatoxylin only.

The cellular elements in *the young and functionally active spleen* show marked differences. The spleens of five kittens, of different ages, were examined—one six weeks old, one ten days, one about a week, one three days old, and one at birth, and in all of them the conspicuous feature is the presence of giant cells. These are most numerous in the seven days' spleen, numbering on a rough estimate about ten thousand in a section, and, as one would expect, the whole spleen was much enlarged. In the ten days old spleen they number about five hundred in a section, in the six weeks' spleen about fifty, in the three days' spleen about forty, and in the spleen at birth about twenty in a section.

In *the Kitten at birth* the giant cells appear to be especially situated in the pulp that surrounds the smaller veins. Their average size is 20 μ in length by 30 μ in breadth. The cell protoplasm has a conspicuous hyaline rim, which has a more pronounced yellow colour than the rest. In most of the cells the nuclei are grouped centrally, but in some as many as eight nuclei are scattered throughout the substance of the cell, and occasionally a knob-like portion of a nucleus that is attached or apposed to the central heap projects beyond the general outline of the cell. A few of the giant cells show vacuoles. Around the giant cell are frequently grouped cells having the characters of erythroblasts. There are with them similar but smaller cells with more deeply stained nuclei.

In *the three days old Kitten* the cellular elements are practically the same in character as those of the newly-born kitten. The nuclei of the giant cells are nearly always collected in a spherical heap near the centre of the cell. A remarkable feature, as in the spleen last described, is the presence of large oblong free masses of pigment both in the pulp and in the veins. Although the colour of the red blood-corpuscles is slightly the darker, there is a strong presumption that the invariable yellow colour of the giant cells and of the erythroblasts is due to the presence of hæmoglobin.

In the spleen of *the Kitten about a week old* the nuclei of the giant cells are usually grouped together near the middle of the cell, and the groups are frequently separated from the protoplasm by a perinuclear space. When the individual nuclei are not close together, they are often seen to be connected by threads of chromatin. Some of the groups of nuclei are practically unstained with hæmatoxylin, while those of neighbouring cells may be deeply stained. The giant cells are much more irregular in outline than

those in the spleens of the younger kittens; the knobs or lobes seem to be formed and bounded by the mouth-like openings on the surface of the cell. Karyokinetic figures are to be made out in the giant cells. When the cells are treated with nuclear stains alone their protoplasm is seen to have a markedly yellow colour, which, since the tissue was fixed with alcohol only, could not be referred to the use of MÜLLER'S fluid or other coloured reagent.

Young giant cells, a fourth or a fifth the size of the larger ones or less, with coarsely granular protoplasm and undivided nucleus, are somewhat numerous. Most of the giant cells are contained within cell spaces that are apparently formed from the connective tissue strands of the pulp stroma. Grouped in clusters among the giant cells are many erythroblasts, which have an unusually large amount of perinuclear protoplasm, which, like that of the giant cells, stains of a characteristic reddish-violet colour; when no staining agent has been used, it has a yellow tinge. Portions of broken down giant cells occur at frequent intervals throughout the pulp and in numbers within the veins, and in the smaller veins especially are quantities of coarse discrete granules that are apparently derived from the giant cells.

In the spleen of *the ten days old Kitten* the giant cells show rather more numerous isolated nuclei than those in the spleens of the other kittens, and many contain erythroblasts within their substance. Similar cells are more frequently seen within foveolæ at the surface of the giant cells than in other spleens, and there is more vacuolation of the giant cells and more erythroblasts grouped round the giant cells than in the two younger spleens; but while more vacuolation of the giant cells is present than in the seven days old spleen the erythroblasts are not more numerous. Within the veins in the interior of the spleen are numerous giant cells, erythroblasts, smaller nucleated red cells, and, in addition to the ordinary red blood-corpuscles and leucocytes, there are masses of granular protoplasm that are apparently derived from disintegrated giant cells.

In the spleen of *the Kitten six weeks old* the giant cells do not show indications of active change as in the two immediately preceding spleens. Their nuclei are usually in a spherical group near the middle of the cell, which is surrounded by a comparatively narrow zone of yellowish granular protoplasm. The nuclear heap occasionally shows slight but large budding, corresponding with which is a large lobing of the cell protoplasm. Protoplasmic corpuscles with the characters of erythroblasts are comparatively scarce.

In the spleen of *the Porpoise* the reticulum is well developed and is more regular than any yet described. The cells composing it are characteristically stellate, and their delicate thread-like processes spring from a comparatively small cell plate. In addition to the rounded meshes there are many long narrow meshes bounded by connective tissue like strands. The whole stroma resembles more connective tissue than endothelium.

The cellular elements of the pulp are mainly of three kinds:—(1) Lymphoid cells;

(2) small hyaline protoplasmic corpuscles, many if not all of which are erythroblasts; and (3) giant cells.

The protoplasmic corpuscles are numerous, occurring both around the giant cells and generally throughout the pulp; they have the usual characters of erythroblasts, a round nucleus with a pronounced intranuclear network and diffuse chromatin, but with no nucleolus, and a more or less narrow rim of perinuclear protoplasm, which is hyaline, of a yellow tint, and which stains very deeply with eosine. Around the giant cells and within the veins are similar but smaller cells, in which the nucleus of the erythroblasts seems to have become condensed, so that it is relatively and absolutely smaller and much more deeply stained: these cells are the ordinary nucleated red blood-corpuscles. There are appearances of karyokinesis in the nuclei of the erythroblasts.

The giant cells resemble those found in other spleens, but they vary more in size and are on the whole smaller; while the larger measure about 30 μ by 18 μ, the smaller measure about 18 μ by 10 μ. Most of the smaller have a single, somewhat large, oval nucleus, and some contain a relatively large number of vacuoles. They are all much lobed and their nuclei show active budding. Frequently they appear to be broken up, so that each isolated nucleus has a covering of protoplasm and forms a separate cell, while a considerable part of the protoplasm is apparently left without any nucleus. Giant cells are not unfrequently seen within the lumen of the veins.

In the spleen of *the Narwhal* the majority of the cells are round protoplasmic corpuscles, consisting of a large round nucleus, that has a well-developed intranuclear network but no nucleolus, which is surrounded by a rim of hyaline yellowish protoplasm that stains of a reddish-brown colour with eosine. These cells are almost certainly erythroblasts; they measure about 10 μ in diameter and their nucleus about 8 μ. The perinuclear rim of some cells is filled with coarse round granules that stain deeply with eosine. There are similar smaller cells, whose nuclei stain very deeply, and which possess a slightly broader rim of perinuclear protoplasm; these are almost undoubtedly nucleated red blood-corpuscles. Both kinds of cells are found in the veins. Giant cells are present in considerable numbers; the smaller consist of a much lobed nucleus or central heap of nuclei surrounded by a rim of hyaline yellow protoplasm; the larger show more pronounced budding of the nucleus. Sometimes a cell resembling the erythroblasts is contained within the substance of the cell near its periphery (as was described in the spleen of the puppy), and similar cells are clustered in numbers around the giant cell, many of them being in apposition with it and contained in cavities on its surface. The nuclei of the giant cells are sometimes completely separated from each other, and there is an appearance, similar to that described in the spleen of the porpoise, as if the giant cell were breaking up to set them free.

In the spleen of *the Rabbit* the reticulum of the pulp varies little from that of the dog; the cells forming it are more numerous in a similar sectional area, and are more delicate. They are typically stellate, their nuclei are often large, oval, and stain faintly

with hæmatoxylin; but sometimes they are small, nearly round and stain deeply. The cell plate and processes are clear and glassy. There are many long connective tissue strands in the stroma, some of which form the walls of the venous sinuses, and with them the stellate cells are directly continuous.

The corpuscular elements in the pulp of the spleen of *a young Rabbit* (probably about half grown) are of four kinds:—(1) Lymphoid cells; (2) giant cells; (3) hyaline protoplasmic corpuscles or erythroblasts; and (4) eosinophilous cells.

The giant cells, which are in considerable numbers, about two hundred in a section, resemble those described in other animals. They show well marked karyokinetic figures. The cell protoplasm shows numerous vacuoles, some of which are apposed to the central nuclear heap. The erythroblasts are not very numerous, while they occupy a position around the giant cells as in other spleens. Eosinophilous cells are comparatively numerous: they often occur in groups that are composed sometimes of as many as twenty cells.

In the splenic pulp of *an adult Rabbit* there occur all the kinds of cells met with in the preceding spleen, and also some cells of another sort. Within the venous sinuses especially, but also in the pulp, are a few cells about a third of the size of the giant cells, consisting of red-stained granular protoplasm that surrounds two or three nuclei, and a variable number of clear round areas which, although something like red blood-corpuscles, seem to be vacuoles. Only about four or five characteristic giant cells occur in a section.

In the spleen of *a second adult Rabbit* the venous sinuses contain many such special vacuolated cells, and the cell substance between the vacuoles contains a large number of yellow pigment grains. The average diameter of these cells is about 16 μ, while the vacuoles measure about 6 μ. There are apparently no giant cells either in the follicles or in the pulp.

In the pulp reticulum of the spleen of *the Rat* there are fewer long connective tissue strands than in that of the rabbit, their place being taken by muscular bundles derived from the trabeculæ, with which the supporting cells are continuous. These cells are not so characteristically stellate, and their processes, which are slightly more thread-like, branch and anastomose more, hence the meshes of the network are relatively more numerous and closer together, while the nuclei are relatively fewer.

The corpuscular elements of the pulp in *the adult Rat* are of four kinds:—(1) Lymphoid cells of different sizes; (2) erythroblasts; (3) giant cells, larger and smaller; and (4) pigment-holding cells.

The giant cells are like those described in other spleens, they number about twenty or thirty in a section. Their nuclei sometimes contain so little chromatin as to be seen only with difficulty after staining with hæmatoxylin, while the diffuse chromatin of the nuclei of the erythroblast sometimes stains so deeply as to hide the network. The central nuclear heap often shows active budding. Those cells that seem to be small giant cells are only about a half or a fourth the size of the larger, but they are much more numerous,

numbering several hundreds in each section. They may have one rather large nucleus, or two or three smaller, and their protoplasm is usually coarsely granular and vacuolated, sometimes showing differentiation into a hyaline rim and a coarsely granular core, and always staining deeply with eosine.

Yellow granules are imbedded in some cells at intervals in the granular pink-stained protoplasm, often accompanied by a single nucleus and several vacuoles. Occasionally a faintly blue-stained nucleus may be seen within a vacuole, and sometimes a round piece of granular protoplasm. The pigment increases in amount until in some cells the granules stud the small remnant of protoplasm surrounding the nucleus and separating the vacuoles.

In the spleen of *a half-grown Rat* there are no giant cells, but numerous smaller vacuolated cells containing pigment, which are like those of the adult rat, but are usually slightly larger and more pigmented. They vary in size from about 12 μ to 20 μ in diameter, and the larger are not of greater size than similar non-vacuolated cells. Some of the vacuoles are twice or thrice the size of a red blood-corpuscle. The remnant of the original protoplasm varies in amount, and the pigment granules appear to be in the protoplasm and not in the vacuoles. (Plate III., fig. 13.) There is usually one nucleus, but sometimes two or three, generally situated near the periphery of the cell. Similar pigmented cells, some of which are vacuolated, are found in the follicles.

In the spleen of *a young Rat* there are a few characteristic giant cells, about ten in a section, but there are apparently no smaller vacuolated cells.

In the spleen of *the Mouse* the reticulum of the pulp resembles very closely that in the rat's spleen; the cell processes are on the whole more plate-like.

A characteristic feature of the spleen of *the adult brown Mouse* is the presence in its pulp of giant cells; this holds good too for the white mouse, as pointed out by J. ARNOLD. In addition to the giant cells there are protoplasmic corpuscles, lymphoid cells, and pigment-holding cells. Lymphoid cells of the follicles show numerous karyokinetic figures; and a similar association of giant cells in the pulp with active karyokinesis in the follicles was noticed in the spleens of the young rat and water-vole.

The giant cells number about fifty in a section, and while some are small, most are large, measuring about 20 μ by 30 μ. Their protoplasm has a markedly yellow tint, and is for the most part coarsely granular, although in some cells there is a very thin hyaline rim. The outline of the cells is sometimes prolonged into spinous projections. In the isolated unhardened giant cell, as seen on examining the fresh pulp teased in methyl salt solution, numerous buds may be seen to project from the cell, perhaps four or five in number; they look like basins turned downwards upon the surface of the cell. The periphery of the giant cell is seen in the fresh condition to have a distinct yellow colour, apparently from the presence of hæmoglobin.

The nuclei of the giant cells after fixation show many different forms, many of which are figured by ARNOLD; the simplest form seems to be that of a horse-shoe shape—sometimes the nucleus has the shape of an hour-glass—but the most frequent arrangement is

that of a ring or hollow sphere. Some cells show many small, deeply stained nuclei, together with a few larger, faintly stained vesicular nuclei. Occasionally in a giant cell there are to be seen the figures of multiple karyokinesis; sixteen or twenty V-shaped loops arranged in a ring around the equatorial plate; or at each end of a nuclear spindle there may be a ring of loops. Sometimes a small, deeply stained nucleus may be seen at a considerable distance from the nuclear heap, and connected with it by a long thin strand of chromatin.

Occasionally an erythroblast seems to be attached by a pedicle of yellow hyaline protoplasm, continuous with its perinuclear protoplasm to the surface of the giant cell, and more frequently erythroblasts are seen to be lodged in depressions of the surface of the giant cell. The erythroblasts show evidence of active division by karyokinesis; often five or six cells lying close together all contain figures, and every field of the microscope shows numerous examples. Nucleated red corpuscles, as well as erythroblasts, are readily recognised in films of the fresh pulp fixed by corrosive sublimate.

In the spleen of *the Guinea-pig* the pulp tissue is in small amount, being in the form of thin partitions that separate wide venous sinuses. Many of these partitions show a thin-walled axial vessel and correspond probably with the ellipsoidal sheath. The pulp tissue proper seems to be mainly collected around the trabeculæ.

The reticulum is almost identical in appearance with that of the rat.

The cellular elements are of three chief kinds :—(1) Lymphoid cells, both uninucleated and multinucleated leucocytes; (2) coarsely granular protoplasmic corpuscles; and (3) the special vacuolated cells. These special cells—the so-called blood-corpuscle holding cells—are very numerous, and occur principally in the venous sinuses. They measure from 8 to 16 μ in diameter. The smaller consist of coarsely granular protoplasm that stains deeply pink with eosine, surrounding a single deeply blue-stained nucleus, and sometimes a round or oval vacuole. The larger cells have similar protoplasm, occasionally three or four large nuclei without any vacuole, but usually a single nucleus laterally placed, several vacuoles and yellow pigment grains. (Plate III. fig. 14.) The vacuoles sometimes take up nearly the whole of the cell, the remnant of the protoplasm and the nucleus together being in the form of a signet ring around them, the outlines of the vacuoles forming a reticulum that occupies the central cavity. The pigment granules are rarely in a vacuole,—they sometimes seem to be adhering to its inner aspect,—but are usually in the protoplasm that surrounds them. They sometimes accumulate so as to fill the whole cell.

In the spleen of *the Hedgehog* the pulp reticulum has a close resemblance to that of the dog and cat; its cells have many broad plate-like processes, and its meshes are much larger than in the spleen of rodents. It is seen to be continuous with the trabeculæ and with the walls of the venous sinuses. As in the spleen of the mouse, the presence of giant cells in the pulp is constant, and so is the presence of large coarsely granular protoplasmic corpuscles (many of which are vacuolated) in the germinal centres of the follicles. In each of seven spleens, obtained at different seasons of the year, considerable

numbers of giant cells occur; they are most numerous in a spleen obtained during hibernation (numbering about 1000 in a section); but they are nearly as numerous (about 800 in a section) in a summer spleen, obtained in July; while in a March spleen they are less numerous (about 600 in a section); and at the beginning of hibernation in one (October) spleen they number about 250, but in another (November) spleen they number about 800 in a section. In each case the size of the spleen varies directly with the number of giant cells.

The other kinds of cells present in the pulp are lymphoid cells, erythroblasts, and a few pigment-holding cells that are found principally within the hilar sheath around the larger arteries.

There are well-marked karyokinetic figures in the giant cells, in the erythroblasts, and in the protoplasmic corpuscles of the follicles. The figures are most numerous, as regards the giant cells, towards the end of hibernation; in a March spleen there are about twenty in a section, occasionally two are seen in one field of the microscope; they were also fairly numerous in the spleens of two hibernating animals during the autumn (October and November) months. The converse obtained as regards karyokinesis in the protoplasmic corpuscles of the follicles; figures were plentiful in the summer and autumn spleens, but scarce or absent in the hibernating spleens.

The nuclei of the giant cells show much variety in arrangement; the most frequent is that of a central heap of closely apposed nuclei, sometimes as many as fifty or sixty in one cell. Often there may be seen a large number of pear-shaped nuclei, not apposed but isolated, yet near together, arranged in a radiating manner, the ends of the stalks of the pear-shaped bodies being near the centre, and their rounded ends near the periphery of the cell. Occasionally all the nuclei are isolated round bodies scattered nearly regularly throughout the substance of the cell. Sometimes an oval nucleus is seen to be connected with the central heap by a long thread of chromatin, being apparently on the point of separation. In some of the giant cells there is a distinct perinuclear space, especially in those cells with large karyokinetic nuclei; and frequently a vacuole or basin-shaped space may be seen on the central nuclear heap, the cavity of the vacuole or basin being continuous with, and apparently a bulging of, the perinuclear space.

Giant cells, together with erythroblasts, are frequently found in the lumen of the larger splenic veins.

In *the Human Spleen* the reticulum of the pulp is intermediate in character between that of the Carnivora and that of the Rodentia, and is more like the former than the latter. The cell processes branch more than in any other spleen, and the nuclei are less numerous, because the cell plates that contain them form a comparatively small proportion of the whole. The cell plates seem to resemble, more closely than in any other pleen, those of connective tissue corpuscles.

A striking feature in the stroma is the presence of large numbers of spindle-shaped muscle fibre cells arranged side by side in the form of sheets, not unlike those in the Amphibians' mesentery. The smallest trabeculæ, that consist almost entirely of muscle,

seem to become frayed out and are applied to the walls of the venous sinuses as layers of long, characteristically spindle-shaped fibres running in the long axis of the sinuses and nearly parallel to each other in the one layer that belongs to each sinus. In transverse section these fibres appear as irregularly pyramidal blocks, of a deep red colour after staining with eosine, some of which contain a nucleus; they are planted by their bases upon what appears to be a connective tissue basement membrane, and thus form a more or less nearly complete ring next the blood stream and are uncovered by endothelium. It follows that the venous channels, along their whole course, have a close relation with the muscular fibres of the trabeculæ. Some, at least, of these fibres appear to terminate in the supporting cells of the stroma. Their appearance in longitudinal view resembles that described by Frey as due to endothelial cells, and in transverse view seems to be like that described as barrel-hoop shaped rings of elastic tissue. (Plate III. fig. 16.)

Four examples of the human fœtal spleen were examined, three of the child and one spleen of a healthy adult.

In the spleen of *the Fœtus between the eighth and ninth month* the cellular elements of the pulp are primarily of three kinds:—Lymphoid cells, protoplasmic corpuscles, and giant or special cells. The lymphoid cells are chiefly uninucleated leucocytes, and are comparatively sparse. The protoplasmic corpuscles are of four kinds:—(1) Smaller hyaline protoplasmic cells, consisting of a deeply stained round nucleus, that possesses a well-developed intranuclear network and measures about 5 μ in diameter, which is surrounded by a comparatively narrow rim of yellow hyaline protoplasm that stains deeply pink with eosine. These are the nucleated red blood-corpuscles. (2) Larger hyaline protoplasmic corpuscles resembling the nucleated red corpuscles, but having a relatively wider rim of perinuclear protoplasm. Their nucleus usually stains a little less deeply, and like that of the smaller cells has no nucleolus. The diameter of the cells measures about 8–10 μ, that of the nuclei about 6–7 μ. These are the erythroblasts of Löwitt. (3) Eosinophilous cells are comparatively numerous. (4) Coarsely granular protoplasmic corpuscles occur plentifully both in the pulp and in the follicles. Their protoplasm stains very deeply with eosine; they have usually only one nucleus, but occasionally two or three; they may or may not possess vacuoles. Some at least of them seem to be young giant cells.

Among the special cells there appear to be intermediate forms between the ordinary giant cells, as found in the spleens of the lower animals, and the smaller special vacuolated cells, as found in the spleens of the rodent animals; these special cells are of four main varieties:—(1) There are a few characteristic giant cells, perhaps three or four in a section, which measure on an average about 30 μ by 20 μ. (Plate III. fig. 15.) Occasionally some of the nuclei are about twice as large as the others and are less deeply stained; these are usually near the middle of the cell, while the smaller more deeply stained nuclei are near the periphery; the latter measure from 4–6 μ. Sometimes a deeply stained nucleus, surrounded by a narrow rim of hyaline protoplasm,

is attached to a giant cell by a conical pedicle of protoplasm continuous with and similar to the perinuclear protoplasm, which hyaline pedicle is contained within a crevice of the granular protoplasm of the giant cell. Such a cell has all the characters of an erythroblast. (2) Other cells more numerous than the ordinary giant cells (perhaps a hundred in a section), have many isolated nuclei of different sizes, most, but not all of which are contained within spaces that appear to be vacuoles; a few seem to be imbedded in the original granular protoplasm. Some of the nuclei in the vacuoles are immediately surrounded by a rim of deeply pink-stained protoplasm. (Plate III. fig. 16.) Frequently the vacuoles near the surface of the cells, perhaps three or four in each, have no nuclei, and from other superficial vacuoles hyaline protoplasmic corpuscles appear to be escaping. (3) Probably the most numerous of the special cells are those consisting of a large number of nuclei, each of which is contained in a capsule-like space or vacuole, and all of which are surrounded by a comparatively thin membrane that consists of little if anything more than the outer portion of the wall of the outermost vacuoles. (Plate III. fig. 16.) In some cells there are as many as thirty nuclei, each contained within a vacuole, and perhaps three or four of these have a rim of perinuclear protoplasm. These special cells vary much in size; their average measurement is about 32 μ by 38 μ. The envacuoled nuclei likewise vary in size; in some cells they are nearly all of comparatively large size, measuring about 8 μ, in other cells they are nearly all about half this size, but in most cells there are both large and small nuclei. The larger nuclei that stain less deeply have sometimes the appearance of karyokinetic change. (4) The fourth variety of the special cells consists of those in which the empty vacuoles are far more numerous than those that contain nuclei; in some cells there are about twenty of the former and only two or three of the latter. Many of these cells closely resemble the special vacuolated cells—the so-called blood-corpuscle holding cells—in the spleen of the rodent animals. (Plate III. fig. 17.)

In the spleen of a Human Fœtus probably between the seventh and eighth month there are a few similar multinucleated special cells which are not quite so large as those in the later fœtus; their average size is about 16 by 20 μ, and three or four may be found in a section. In the follicles are somewhat numerous coarsely granular protoplasmic corpuscles. Scattered throughout the pulp are many nucleated red blood-corpuscles, most of which appear to belong to the blood, but there are only a few erythroblasts.

In another *fœtal spleen at about the seventh month* similar special multinucleated cells occur in very small numbers; and in slightly larger numbers the smaller vacuolated special cells like those that are found in the spleens of the rodent animals, but there are no characteristic giant cells. Eosinophilous cells are somewhat numerous; nucleated red blood-corpuscles are still more numerous, but erythroblasts are scarce.

In the spleen of *a fourth Human Fœtus between the fourth and fifth month* there are a few somewhat small but otherwise characteristic giant cells, about four or

five in a section. Coarsely granular protoplasmic corpuscles occur in the follicles and in the pulp; in the latter are also numerous nucleated red cells and a few erythroblasts.

In the spleen of *the Child* the cellular elements of the pulp are mainly of four kinds:—Lymphoid cells, eosinophilous cells, numerous nucleated red blood-corpuscles and erythroblasts, and special cells of the type of giant cells.

The special cells are of three kinds:—(1) There is a very small number of coarsely granular cells like small giant cells, their average measurement being about 20 by 15 μ. They have usually two or three nuclei that vary considerably in size, and may or may not have vacuoles. (2) A few cells resemble those characteristic of the spleen of the eight months' fœtus; most of the vacuoles contain nuclei, the empty ones are in the proportion of one to three. (3) By far the most numerous are cells consisting of one or two oval nuclei and many vacuoles which are surrounded by a variable amount of granular protoplasm that stains somewhat deeply pink with eosine. Their usual size is about 20 μ in diameter, but they may be 30 μ in diameter, and sometimes they are as large as 42 by 18 μ. (Plate III. figs. 18, 19, and 20.) There may be four or five small vacuoles close to a central nucleus, all being surrounded by a broad band of coarsely granular protoplasm. Occasionally there are a few small vacuoles, together with a long oval nucleus, in a peripheral band of protoplasm, while the middle of the cell is occupied by a large vacuole that sometimes contains a round protoplasmic corpuscle whose diameter is about 10 μ and that of its nucleus about 7 μ. More frequently, however, the cell contains so many vacuoles that its substance seems to consist almost entirely of their apposed capsule-like walls; there is usually in addition a single almost elliptical nucleus surrounded by a little granular protoplasm at the periphery of the cell. These cells occur in large numbers within the venous sinuses, and the red blood-corpuscles by which they are surrounded adhere to their surface. The larger cells, found especially in the pulp, have usually two oval nuclei imbedded in a small amount of granular protoplasm and situated near the middle of the cell; around them are frequently seen numerous erythroblasts. (Plate III. fig. 21.) Characteristic giant cells occur in some of the follicles; they vary from about 50 by 20 μ to about a third of that size. In the pulp around the follicles are similar but smaller giant cells; they have usually less protoplasm, more vacuoles, and a smaller nucleus.

In the spleen of *a Human Adult*—a healthy man—the cellular elements of the pulp are lymphoid cells, eosinophilous cells, and coarsely granular protoplasmic corpuscles. The latter are most numerous near the follicles, while they occur in large numbers within the follicles. Their average size is about 8 μ in diameter; they have usually a single round nucleus that measures about 6 μ, which has no nucleolus, but a well-marked intranuclear network. Occasionally one of the larger cells is seen to contain a large-budded nucleus. The smaller cells sometimes show ill-formed karyokinetic figures. These cells thus resemble very small giant cells rather than erythroblasts.

There were no characteristic giant cells found in this healthy spleen.

Commentary.

Our more accurate knowledge of the structure of the reticulum of the splenic pulp dates from 1875, when Dr KLEIN * published his observations on the structure of the spleen. My observations are almost entirely confirmatory of his; I am in doubt, however, as to the exact nature of the cells that form it, for their character seems to me to be intermediate between those of endothelial cells and flattened branched connective tissue corpuscles, and rather to resemble the latter, as seen for example in tendon or in the cornea, than the former. I have never seen any indication of the production of lymphoid cells by budding from the cells of the matrix that he describes,† nor the presence of pigment and coloured blood-corpuscles in the cell plates; and I cannot accept his opinion that the giant cells form a part of the membranous stroma.‡

The chief interest in the study of the cellular elements of the splenic pulp seems to centre around those appearances that by some observers are believed to indicate a destruction, and by others a production of coloured blood-corpuscles.

The following evidence appears to me to be adverse to the theory of phagocytosis as regards the Giant Cells:—

(1) They occur in the spleen at the time when blood formation has been proved to be taking place in it,—during late embryonic and early extra-uterine life,—just at those periods when one would expect loss of blood to be most disadvantageous. Although VAN DER STRICHT § considers that they devour the extravasated nuclei alone of erythroblasts, DENYS || believes that they take up the entire erythroblasts. (2) *They occur in the follicles*, where there are few if any coloured blood-corpuscles, and yet they do not take up the lymphoid cells. Erythroblasts are, however, found in the follicles around the giant cells, and in the mouth-like openings at their periphery. (3) Although the giant cells contain many empty vacuoles, we have never seen any partially digested nuclei in them. (4) If, as is more generally believed, the nuclei of nucleated red cells are absorbed and not extruded, there can be no free nuclei for the giant cells to devour. (5) Although the isolated nuclei that the giant cells contain, which are apparently identical in character with those of nucleated red cells or of erythroblasts, have no obvious perinuclear protoplasm of their own, as a rule, yet when near the periphery of the giant cell they have often a distinct rim of hyaline protoplasm, and are, in fact, entire erythroblasts. (6) The nuclei of contained erythroblasts may sometimes be seen to be connected with the central nuclear heap of the giant cell by a long and slender strand of chromatin.

Summary regarding the Splenic Pulp.

(1) The reticulum of the splenic pulp is formed by the anastomosis of the expanded

* KLEIN (16), p. 368.
‡ KLEIN (17), p. 426.
|| DENYS (24), p. 159.
† KLEIN (16), p. 369.
§ VAN DER STRICHT (48), p. 88.

processes of nucleated plate-like cells, and is continuous with the supporting framework of the spleen.

(2) The cellular elements of the pulp may be classified as follows :—

1. *Lymphoid Cells.*
   - (1) Uninucleated.
   - (2) Multinucleated.
2. *Protoplasmic Corpuscles.*
   - (1) Coarsely granular.
   - (2) Hyaline.
     - (a) Erythroblasts.
     - (b) Nucleated red cells
   - (3) Eosinophilous cells.
3. *Pigment-holding Cells.*
4. *Special Cells.*
   - (1) Giant cells.
   - (2) Multinucleated vacuolated cells.
   - (3) Uninucleated vacuolated cells.

(3) *The lymphoid cells* are nearly all uninucleated, with little, if any, peripheral protoplasm, and resemble the small lymphoid cells of the outer zone of the follicles.

(4) The multinucleated lymphoid cells have a considerable amount of finely granular protoplasm that stains faintly, if at all, with eosine; and they are probably derived from the blood.

(5) The protoplasm of the protoplasmic corpuscles stains deeply with eosine.

(6) Erythroblasts and nucleated red cells are more numerous in those spleens that contain giant cells, and as a rule they appear to be most numerous in those that contain most giant cells.

(7) Erythroblasts are sometimes seen in the substance of the giant cells, sometimes in bulgings of their surface, and often in mouth-like openings on their surface.

(8) The erythroblasts multiply by karyokinesis.

(9) The hyaline perinuclear protoplasm of the erythroblasts seems to be slightly tinted with hæmoglobin as Bizzozero * maintained.

(10) The pigment of *the pigment-holding cells* either occurs in the form of granules imbedded in a basis of coarsely granular protoplasm, or it, along with a nucleus, entirely fills the cell. It is probable that the pigment granules have been taken up by the pigment-cells, that the pigment-cells are phagocytes, and of the nature of leucocytes.

(11) *Giant cells* occur, probably invariably, in the spleen of Mammals during early extra-uterine life, and usually also in late intra-uterine life. They occur in considerable numbers in the spleen of some small Mammals, for example the mouse, the rat, and the hedgehog, during adult life. And they may occur in small numbers in the spleen of individual instances of other adult Mammals, for example the dog and the cat.

* Bizzozero, cited by Muir (47), p. 502.

(12) Cells apparently homologous with the giant cells of the mammalian spleen were found in the spleen of the tortoise.

(13) They seem to be a concomitant of the blood-forming activity of the spleen; they are associated with numerous erythroblasts and nucleated red cells in the pulp, and frequently with active karyokinesis in the follicles.

(14) They multiply usually by karyokinesis, but they probably divide sometimes by simple fission.

(15) They have usually a large central nuclear heap that gives off pyriform buds.

(16) The nuclear buds, when isolated in the cell, resemble the nuclei of nucleated red blood-corpuscles or of erythroblasts; while near the middle of the giant cell they are somewhat small, stain deeply, and resemble the nuclei of the nucleated red blood-corpuscles; when near the periphery of the cell they are larger, they stain faintly (they thus resemble the nuclei of erythroblasts), and may be surrounded by a special covering of hyaline protoplasm.

(17) The greater part of the protoplasm of the giant cells is coarsely granular, but there is a more or less narrow hyaline rim which has a faint but distinct yellow colour like that of the perinuclear protoplasm of the erythroblasts, and similar to, only not so deep as that of the red blood-corpuscles.

(18) The giant cells usually possess vacuoles that appear to mark the former position of detached nuclear buds.

(19) The vacuoles situated near the periphery of the giant cell sometimes contain erythroblasts.

(20) The ruptured vacuoles on the surface of the giant cells have the character of mouth-like openings, and in them erythroblasts are frequently lodged.

(21) The giant cells probably never contain non-nucleated red blood-corpuscles.

(22) The giant cells often enter the splenic vein along with the proper corpuscular elements of the blood.

(23) They occur in the follicles, and some apparently pass into the pulp from the follicles.

(24) In the pulp they are often contained in cell spaces formed apparently by connective tissue strands, and it is possible that these cell spaces persist, after the disappearance of the giant cells, as the blood spaces of the pulp.

(25) It is probable that the giant cells are not phagocytes, but that they are producers of erythroblasts.

(26) *The special multinucleated vacuolated cells* were found in the spleen of an eight months' human fœtus.

(27) They are apparently derived from giant cells whose nuclei have become isolated, and inclosed each in a vacuole or capsule-like nuclear space.

(28) In the larger cells a few of the superficial vacuoles alone are empty; in the smaller a few only of the vacuoles contain nuclei.

(29) After all the nuclei except one or two have disappeared from the vacuoles

the cell resembles the special uninucleated vacuolated cells. Thus the multinucleated vacuolated cell seems to afford a connecting link between the uninucleated vacuolated cell and the giant cell.

(30) *The special uninucleated vacuolated cells* were found in the spleens of the rabbit, rat, guinea-pig, human fœtus (at the seventh and at the eighth month), and child.

(31) They appear to be produced from larger or smaller giant cells, by the extrusion of nuclear buds, the number of vacuoles increasing until there is little of the original protoplasm left, and the amount of nuclear substance gradually diminishing.

(32) It is doubtful whether these cells ever contain non-nucleated red blood corpuscles; but erythroblasts are occasionally seen within their vacuoles.

PART II.

On the Physiology of the Spleen and Blood Formation.

Chapter V.

Foa and Salvioli* have shown that the nucleated red cells in the embryonic liver bear a direct numerical relation with the erythroblasts and with the giant cells in that blood-forming organ; they have given reasons for believing that the erythroblasts are developed from the giant cells, or, as they term them, hæmatoblasts; and they have observed similar cells, affording evidence of a similar process, in the fœtal spleen and lymphatic glands.

As regards the spleen, we have, we think, already produced confirmation of the probability of the truth of the theory that its giant cells produce erythroblasts.

If the endogenous development of erythroblasts within giant cells is an important mode of blood production, one would not unreasonably expect to find the mother cells in those positions where blood formation is known to be actively progressing.

The positions in which mammalian blood formation is known to occur may be summarised as follows:—

(*a*) In the vascular area of the fœtal membranes.

(*b*) Within the fœtus during early intra-uterine life.

- (1) In the liver.
- (2) In the subcutaneous connective tissue.

(*c*) During late intra-uterine life.

- (1) In the spleen.
- (2) In the bone marrow.
- (3) In the lymphatic glands.

* Foa and Salvioli (38), p. 125.

(*d*) In early extra-uterine life.

(1) In the spleen.

(2) In the bone marrow.

(*e*) In adult life.

(1) In the bone marrow.

In each one of these situations, at the time when blood formation is known to occur in it, the presence of giant cells has been demonstrated.

Blood formation in the vascular area is associated with mesoblastic cells, containing a central ball of nuclei—the vaso-formative cells of RANVIER.* Similarly, large multinucleated cells or hæmatoblasts have been described by WISSOZKY† in the allantois of the embryo rabbit; and they are considered by him to produce small uninucleated hæmatoblasts — the erythroblasts — by a process of endogenous formation.

In the liver of the three months' human fœtus, NEUMANN,‡ in 1874, described appearances of the giant cells which, as he believed, indicate an endogenous development of nucleated red blood-corpuscles within them—the mother cells. He also alludes§ to similar observations by REICHERT, who found in the fœtal liver of the hen "mother cells filled with a younger generation." Recently, an able paper has been published by OMER VAN DER STRICHT,‖ on the development of the blood in the embryonic liver, in which he states that giant cells appear in the liver at the moment when the organ partakes actively in the formation of red blood-corpuscles, and accounts for the presence of the nuclei of erythroblasts within the giant cells on a theory of phagocytosis.

The presence of large multinucleated vacuolated cells, tinted with hæmoglobin, in the subcutaneous connective tissue, was first described by E. A. SCHÄFER¶ in the newly born rat. Within them he described the formation of non-nucleated red blood-corpuscles. If, as would appear from his description, he examined these cells in the fresh condition only, and without staining, the newly formed red blood-corpuscles may have contained nuclei that were not revealed.

Giant cells in the bone-marrow were first described by BIZZOZERO;** and in the liver and spleen by KÖLLIKER and REMAK.†† The mode of production of red blood-corpuscles from giant cells in the embryonic liver, spleen, and lymph glands, and in the adult bone-marrow, according to the view advanced by FOA and SALVIOLI, is described by BIZZOZERO‡‡ as follows:—From the nuclear heap of the giant cell a bud springs; this, after it has increased in size, becomes isolated, makes its way to the periphery of the cell, where it is surrounded by a layer of hyaline substance derived from the protoplasm of the giant cell, and forms a projecting bud on the surface of the cell; it ultimately becomes detached as

* RANVIER (45), p. 640.
‡ NEUMANN (28), p. 469.
‖ VAN DER STRICHT (48), p. 60 and p. 88.
** BIZZOZERO (31), p. 30.
‡‡ BIZZOZERO (31), p. 30.
† WISSOZKY (42), p. 479.
§ NEUMANN (28), p. 448.
¶ SCHÄFER (35), p. 243.
†† REMAK (27), p. 99.

a small daughter cell, consisting of a nucleus enveloped in a layer of hyaline substance, that later becomes coloured with hæmoglobin, and so an erythroblast is formed. In one respect only I differ from this view, as I believe that the perinuclear protoplasm of the erythroblast is, in the spleen, tinted with hæmoglobin before the cell escapes. Alluding to these observations, which are practically the same as NEUMANN made on the giant cells of the liver, BIZZOZERO * remarks that the usual association of giant cells with nucleated red blood-corpuscles, pointed out by FOA and SALVIOLI, affords only presumptive evidence in favour of their view, and that it would have been much more convincing if one had seen, what he believes none has ever seen, the protoplasm of the giant cells coloured with hæmoglobin, or the nucleated red cells already coloured while attached to the giant cells. Both of these phenomena we are able, as we believe, to demonstrate.

A case of Leucocythæmia, recorded by Dr ROBERT MUIR,† the spleen from which I examined, has a special interest with reference to blood formation. Blood taken from the finger, on many occasions during life, always showed large numbers of nucleated red cells. The spleen was much enlarged, but the bone-marrow and liver were unaffected.

The Spleen contains numerous giant cells (about twenty or thirty in a section half-an-inch square), very numerous erythroblasts and nucleated red blood-corpuscles, and large numbers of special uninucleated vacuolated cells like those in the spleen of the child. The giant cells have the ordinary characters,—coarsely granular protoplasm, a central nuclear heap, vacuoles, mouth-like openings, many of which contain erythroblasts. Their average measurement is probably about 40 μ by 20 μ. Occasionally the central nuclear heap is circumscribed by a regular outline, but usually it gives off pyriform or Indian club-shaped buds. (Plate III. fig. 22.) The buds vary much in size, but in the largest the head of the club is as large as an erythroblast, and often it is seen to be contained in what appears to be a perinuclear space. Frequently an erythroblast is seen to be connected with the giant cell by the stalk of the pyriform nucleus, attached to the central nuclear heap, and by a pedicle of protoplasm apparently continuous with the protoplasm of the giant cell.

The mediastinal lymph glands were greatly enlarged, but they contained no giant cells, and few, if any, nucleated red cells or erythroblasts. Thus it is probable that the nucleated red cells found in the blood had their origin in the spleen.

On Artificial Anæmia in Dogs.

The following is a précis of the experiments of BIZZOZERO and SALVIOLI,‡ which prove the frequent occurrence of nucleated red cells in the spleens of dogs that have been rendered anæmic.

* BIZZOZERO (31), p. 32. † MUIR (47), p. 480 (Case 54).

‡ BIZZOZERO and SALVIOLI (30), p. 600.

No. of Experiment.	Hæmorrhage, percentage of body weight. Days' interval.	Hæmoglobin fell to	Result on Spleen as regards Nucleated Red Cells.
I.	**2·9 per cent.** Two days. **3·7 per cent.** Three days.	43·5 per cent.	Very numerous.
II.	**3·94 per cent.** Four days.	58·4 per cent.	Sparse.
III.	**3·7 per cent.** Three days. **2·6 per cent.** Six days. **1·1 per cent.** Two days.	40 per cent.	Moderate numbers.
IV.	**3 per cent.** Four days. **2·48 per cent.** Four days.	46 per cent.	Sparse.
V.	**1·73 per cent.** Five days. **2·08 per cent.** Two days.	45 per cent.	Extremely large numbers.
VI.	**1·52 per cent.** Ten days.	62 per cent.	None.
VII.	**2·98 per cent.** Four days. **3·21 per cent.** Five days. **2·14 per cent.** Three days.	58·2 per cent.	Considerable numbers.
VIII.	**3 per cent.** Four days. **2·55 per cent.** Two days. **2·1 per cent.** Two days.	42·7 per cent.	A few.
IX.	**3·5 per cent.** Four days. **3 per cent.** Five days. **2·85 per cent.** Four days. **3·1 per cent.** Six days. **2·78 per cent.** Five days. **2·44 per cent.** Four days.	25·7 per cent.	Enormous numbers.

No. of Experiment.	Hæmorrhage, percentage of body weight. Days' interval.	Hæmoglobin fell to	Result on Spleen as regards Nucleated Red Cells.
X.	**2·3 per cent.** Seven days. **3 per cent.** Three days. **3 per cent.** Two days. **3 per cent.** Three days. Three days.	39 per cent.	Great numbers.

They describe the naked eye appearance of the spleen after copious hæmorrhage as characteristic; it is rose-coloured and much swollen. While they examined the splenic pulp microscopically in the fresh condition, both with and without indifferent fluids, they apparently attended to the nucleated red cells alone, and they do not record any examination of sections of the spleen.

Dr Robert Muir * produced anæmia in three dogs, and observed especially the accompanying changes in the red bone-marrow. He was good enough to give me the spleens of these dogs for microscopic examination, and the following is a summary of his observations that bear especially on that examination.

No. of Experiment.	Hæmorrhage, percentage of body weight. Days' interval.	Result on Blood.		Result on Spleen; Nucleated Red Corpuscles.
		1. No. of Red Corpuscles.	2. Nucleated Red Corpuscles.	
I. and III.	**2 per cent.** Seventeen days. **2·5 per cent.** Six days. **2·3 per cent.** Three days. **2·3 per cent.** Eight days. On 3rd day. On 8th day.	(7,460,000) 2,884,000 4,280,000	None. Present during last 12 days.	 A few.
II.	**2·8 per cent.** Four days. **2·5 per cent.** Nine days. On 3rd day. On 9th day.	(6,698,000) 2,451,000 3,311,000	 Present during last 11 days.	 A few.
IV.	**2·85 per cent.** Four days. **2·5 per cent.** Nine days. On 2nd day. On 9th day.	(5,830,000) 2,555,000 3,379,000	 Present during last 9 days.	 Present.

* Muir (47), p. 491.

With regard to Dr MUIR's estimate of the number of nucleated red cells in the spleen, obtained by examining a scraping of its surface, it must be borne in mind that such a preparation contains elements derived from other sources than the pulp (those from the follicles being in great numbers), and cannot, therefore, be fairly compared with a fresh preparation of bone-marrow, that corresponds, practically, solely with the pulp.

In *the Spleen of the Dog from Experiment II.* there are large numbers of giant cells,—on a rough computation about 1000 in each section through its thickest part. They present the usual characters, but their outline shows an unusually large number of mouth-like openings. Their nuclei exhibit much budding; perhaps the most frequent arrangement is a rosette of pyriform buds. A few cells show karyokinetic figures. There were no giant cells observed within the follicles. (Plate III. fig. 23.) There are enormous numbers of erythroblasts and nucleated red cells present, many of the former being clustered around the giant cells. There were very many more nucleated red cells and erythroblasts in the blood of the splenic vein than in that of the artery. The protoplasm, both of the giant cells and of the erythroblasts, has a marked yellow colour. A few eosinophilous cells are present in the pulp.

In *the Spleen of the Dog from Experiments I. and III.* there are equally large numbers of giant cells—about 1000 in a section. Their outline has fewer mouth-like openings (than in Expt. II.), but their nuclei show similar budding. The typical arrangement is a rosette of pear-shaped nuclei, their apices, which point inwards, being frequently connected together; occasionally a single cell has two such rosettes, one arranged around each end of a somewhat thick stem. Rarely a giant cell may be seen within a follicle. Almost all the cells in the follicles are leucoblasts, and this fact, together with the presence of numerous giant cells in the pulp, remind one of the appearances in the spleen of the young Mammal. There are very large numbers of erythroblasts and nucleated red cells, but not so many as in the previous spleen; and there is a comparatively small number of these cells in the veins. Pigment-holding cells are present in large numbers, and also globular masses of free, or apparently free, pigment. Eosinophilous cells were not found. A considerable amount of a coarsely granular substance was seen in the veins, some of it collected into round clumps, and some of it in the form of discrete coarse granules; as it so nearly constantly occurs in the veins in association with the giant cells in the pulp, it is suggestive that it may possibly result from the breaking down of the inner coarsely granular portion of the protoplasm of the giant cells.

In the Spleen of the Dog from Experiment IV., the most striking naked-eye character of which is its pale lemon-yellow colour, there are considerable numbers of giant cells, but not so many as in the other two spleens—numbering, on a rough estimate, about 500 in a section. This spleen is smaller than the other two, and the body-weight of the dog from which it was obtained was a third less.

Many of the giant cells are smaller—only about half the average size of those in the

other two spleens. They have a more irregular surface than those of the spleen immediately preceding, and about the same as in the spleen of Expt. II. Their protoplasm shows a conspicuous division into hyaline rim and coarsely granular core. They were seen a few times within follicles, frequently in the veins within the spleen, and one was seen in the peripheral blood-sinus of an ellipsoid. There are present in the pulp enormous numbers of mature nucleated red cells, but a comparatively small number of erythroblasts. Occasionally a nucleated red cell may be seen to have two nuclei. A large number of nucleated red cells, in different stages of maturity, are seen within the veins. Many coarsely granular protoplasmic corpuscles are present; they are grouped in the follicles as in the spleen of the child, and are scattered throughout the pulp, but are especially numerous in the neighbourhood of the follicles. As regards their general characters, they may be compared with small uninucleated giant cells. They sometimes show karyokinetic figures. Some of the larger are vacuolated, and resemble the special uninucleated vacuolated cells characteristic of the spleen of the child. There are a few eosinophilous cells and a few pigment-holding cells present; the latter are mainly in the follicles. Scattered throughout the pulp are large numbers of small lymphoid cells, or uninucleated leucocytes. The germinal centres of the follicles are relatively small, and there are many small lymphoid cells scattered among its leucoblasts.

Two Experiments on Anæmia in Dogs.

In following up the indications obtained from the evidence detailed up to this point, I bled two dogs, with a principal object of examining the giant cells, that I expected to make their appearance as a result of the bleeding, in the fresh condition. Both experiments were on adult fox-terriers, and they were conducted as nearly as possible in the same way. The dogs were put on a fixed diet, and their blood was examined at the same hour each day, and with the same time relation to feeding. When the observations were constant, the same, or nearly the same, percentage of the body weight of blood was removed in each case by incising the external jugular vein. Ether was used as an anæsthetic. A curious fact was noticed in each bleeding—that the last portion of blood withdrawn clotted immediately it passed from the vein into the cannula, so that the latter became blocked. The routine followed in the examination of the blood was as follows:—The interior of the lobe of the ear was cleansed, and a small incision was made with a sharp scalpel; the number of the corpuscular elements was estimated by means of the Thoma-Zeiss hæmocytometer, diluting the blood with methyl salt solution; the percentage of hæmoglobin was estimated with Gowers' hæmoglobinometer; and the specific gravity was ascertained by Haycraft's method; cover glass films of blood were dried in the air and afterwards stained, and fresh preparations of blood were made by allowing a drop to be spread in a thin layer on a slide by the weight of a cover glass and ringing the cover glass with oil. The wounds of the operations were treated

antiseptically, and, except in one case, healed by first intention. After each operation, two pints, or more, of milk were given immediately, and as much water as the animal desired.

Experiment I.—Part I.

Day of Experiment.	Specific Gravity.	Per Cent. Hb.	Red Corpuscles.	Leucocytes.	Nucleated Red Cells.	Weight in Kilo.
1	1057	72	6,590,000	11,000	None.	6·5
3	1058·3	72	6,640,000	12,000	,,	...
5	1059	72	6,680,000	12,000	,,	6·6
7		**Blood abstracted, 2·4 per cent. of body weight.**				
Four hours later.	1049	60	4,880,000	36,000	None.	6·47
8	1053	60	5,840,000	34,000	,,	,,
9	1054·5	60	4,330,000	15,000	,,	...
10	1054·2	62	5,210,000	16,000	,,	...
12	1053	58	5,640,000	20,000	,,	...
14	1053·3	...	5,135,000	16,000	,,	6·47
16	1053·3	54	5,080,000	18,000	,,	...
19	1055·7	54	4,987,000	20,000	,,	6·5
20		**Blood abstracted, 3 per cent. of body weight.**				
21	1050	38	3,560,000	32,000	Very few ($\frac{1}{4}$).	6·5
22	1050	36	3,057,000	32,000	Few (30).	...
23	1050	38	3,720,000	28,000	Few (20).	...
24	1050	38	3,900,000	26,000	Very few (5).	...
26	1051	40	3,760,000	...	None.	6·7
28	1050	40	3,960,000	26,000	,,	...
30	1051·2	40	4,040,000	16,000	,,	...

Note.—The figures in the column "nucleated red cells" indicate the average number of cells seen in single films ($\frac{1}{4}$ means one in four films).

There were no poikilocytes observed at any time; but *on the* 10*th day*, three days subsequent to the first bleeding, and afterwards, the red corpuscles varied in size slightly, a few being 5, 6, or 7 μ.

On the 21*st day*, the day following the second bleeding, the red blood-corpuscles showed a slight tendency to invagination; and nucleated red cells were seen for the first time during the experiment, one or two being found after careful search through several films.

On the 22*nd day*, in a plain preparation of blood, there were seen several large cellular bodies, one much larger than the others, which seemed to be giant cells. The largest cell was much lobed, large buds projecting from its surface in all directions, giving an appearance like that described in the giant cell of the spleen of the mouse, when examined fresh in methyl salt solution. A small round cell was in contact with the large cell, but apparently detached from it. The peripheral part of the protoplasm of the large cell was tinted yellow here and there, as also was the whole of the protoplasm of the small cell, and the latter seemed to contain a round nucleus. As the blood-corpuscles ran together, other large cells were revealed, lying in spaces comparatively free

from red cells. One special cell, somewhat smaller than the average, did not possess any buds, but the nuclei were visible grouped in a heap in the middle of the cell, and were surrounded by a comparatively narrow band of hyaline protoplasm which reached to the periphery, and had a deep yellow colour. The fresh preparations showed a very rich felt work of fibrin and very many blood plates, mostly in clusters. The films contained several nucleated red cells, perhaps about thirty in each. Their protoplasm stained more deeply with methyl blue than that of the majority of the non-nucleated forms. Some of the latter, however, as MUIR has recorded, show a similarly deep staining, with an irregular surface as if of softer consistence than the majority, suggesting that they had recently been in the nucleated condition.

On the 23rd day several large cells were seen in a plain preparation of blood. The nucleated red cells were not so numerous as on the preceding day, perhaps about twenty in a film. Blood plates were very numerous.

On the 24th day one large special cell was seen in one of two plain preparations of fresh blood. There was a marked reduction in the number of nucleated red cells; about five were seen in each film. The red blood-corpuscles varied much in size.

On the 26th day there were no large cells seen in several plain preparations of blood. The nucleated red cells had apparently also disappeared; but the films contained many darkly stained softer red corpuscles.

Between the second bleeding and the third an interval of forty-two days was allowed to elapse.

Experiment I.—Part II.

Day of Experiment.	Specific Gravity.	Per Cent. Hb.	Red Corpuscles.	Leucocytes.	Nucleated Red Cells.	Weight in Kilo.
1	1052·2	54	5,740,000	18,000	None.	6·6
2	...	...	5,840,000	14,000	...	...
3	1052·2	54	5,893,000	16,000	None.	...
6	1052·2	54	5,866,000	14,000	„	6·6
7		**Blood abstracted, 3 per cent. of body weight.**				
8	1050·8	38	4,046,000	28,000	None.	6·4
9	1050·5	40	4,120,000	11,000	„	...
10	The dog was killed with chloroform.					

Note.—Day 1 of part 2 corresponds with day 56 of part 1.

On the three days before the last bleeding, large special cells were found in the blood, on an average one in a preparation.

On the 8th day, the first day after the bleeding, in six plain preparations (four of which were examined on SCHÄFER'S warm stage) there were seen many large cells, about thirty or forty in each. Some were found in the hæmocytometer preparation: one was seen to occupy about the half of a ruled square. This had a blue-stained central portion

and a yellow periphery; in the middle of the cell, oval outlines were visible, apparently those of nuclei, and on its surface were several blunt processes or buds. Most of the other special cells were smaller, about eight times the size of a red blood-corpuscle. In a preparation made with methyl salt solution and osmic acid several special cells were seen; one was very large, markedly yellow, and covered all over with buds.

On the warm stage they exhibited amœboid movement at their periphery in a specialised rim of the protoplasm. In one instance there was seen a bud, containing what seemed like a rounded collection of very coarse granules, an appearance probably due to the nodes of an intranuclear network, which became detached so as to form a small round cell. In one of the large cells vacuoles were observed, and in several, creek-like fissures were seen in their outline. Neither the red blood-corpuscles nor the leucocytes showed any tendency to adhere to the surface of the large cells. There was a very rich felt work of fibrin in the plain preparations.

Nucleated red cells were not found in the films of blood.

On the morning of the 9th day the blood contained very many large cells, on a rough estimate about forty or fifty in a preparation. They have a characteristically hyaline and glittering surface, characters more marked than of the somewhat similar surface of the leucocytes, and quite unlike those of the surface of the clumps of blood plates. In one case a pear-shaped bud was connected with a large cell by its long pedicle that was contained in a kind of channel in the protoplasm of the large cell; the pedicle was seen to give way, and there was left a small round cell, with a coarsely granular centre, lying in a depression on the surface of the large cell. Two similar small cells were seen in one instance to come into apposition with a large cell, but almost immediately thereafter they became again widely separate. The nuclei of the small cells show the remarkable dotted appearance to which reference has been made, and each is surrounded by a narrow rim of hyaline amœboid protoplasm. There was seen a very strong fibrin network.

On the afternoon of the same day (9*th*) the number of large cells in the blood was very much reduced. There were no nucleated red cells found in the blood on this day.

It is difficult satisfactorily to explain the absence of nucleated red cells from the blood, if it be considered that the small cells, which are budded off on the warm stage from the large cells, are probably erythroblasts. These large cells are in abnormal conditions, and it may be that contact with the glass, together with the heat, may have precipitated the detachment of buds or accelerated a process that normally occurs slowly.

On the 10*th day* the dog was killed with chloroform.

The Spleen measured 4½ inches in length and weighed 13 grammes; it was of a dark red colour; it was slightly soft and rather full of blood. A scraping of its surface was examined in methyl salt solution, and, after dilution with hydrocele fluid, preparations

were examined on the warm stage. Erythroblasts and nucleated red cells in fairly large numbers and a few giant cells were recognised in all the fresh preparations, and also in films of the pulp fixed in saturated solution of corrosive sublimate and subsequently stained. The giant cells in the fresh preparations were hyaline in appearance and much budded, like those of the blood; but amœboid movement was not observed in any of them on the warm stage.

Sections of the Spleen showed comparatively few larger giant cells, perhaps about sixty in each; and they do not exhibit the appearances characteristic of active change. There are smaller giant cells present in considerable numbers; they are as a rule nearly round, and have a small and but little lobed nuclear heap. The larger giant cells have an unusually distinct perinuclear space. A giant cell and a few coarsely granular protoplasmic corpuscles are occasionally seen in the follicles. There is a very small number of erythroblasts and of nucleated red cells, but they are apparently almost, if not quite, as numerous in proportion to the number of giant cells as in the other spleens. There was seen in the veins a very small number of nucleated red cells. A few pigment-holding cells were found in the follicles, and numerous pigment masses in the pulp.

The Bone-Marrow as seen in fresh preparations contained many erythroblasts, nucleated red cells, and giant cells. The marrow of the ribs contained proportionately more of these cells than that of the femur, indeed it seemed to be composed entirely of them, and could be readily squeezed out from the cavity of the rib as a thin fluid. The giant cells appeared to be less hyaline than those of the blood and spleen, and to have fewer buds. Amœboid movement on the warm stage was not seen. Sections of the bone-marrow of the femur show numerous giant cells, on a rough estimate about 150 in each section. The yellow colour of their protoplasm is nearly as deep as that of the red blood-corpuscles. A few grains of pigment are scattered here and there. Very many erythroblasts and nucleated red cells are present, far more in proportion to the number of giant cells than in any spleen I have examined.

In *a Lymphatic Gland taken from the neck* there are a few erythroblasts and nucleated red cells which appear to be colourless. There are a few somewhat large multinucleated protoplasmic cells, like small giant cells, perhaps one or two in a section. In the sinuses are large numbers of coarsely granular, uninucleated, protoplasmic corpuscles that stain somewhat deeply with eosine; their average size is about 10 m. There are numerous pigment-holding cells present.

In *a Mesenteric Lymphatic Gland* there are erythroblasts in small number. In the sinuses there are in addition numerous uninucleated vacuolated cells like those characteristic of the spleen of the child; and there are cells without vacuoles but otherwise similar.

Films of the blood taken from the splenic vein while the dog was dying did not contain any nucleated red cells.

Experiment II.

Day of Experiment.	Specific Gravity.	Per Cent. Hb.	Red Corpuscles.	Leucocytes.	Nucleated Red Cells.	Weight in Kilo.
1	1059·5	84	6,670,000	7,000	None.	8·6
2	1059	84	6,740,000	8,000	„	...
3	1058·5	84	6,780,000	6,000	„	8·6
4		**Blood abstracted, 2·4 per cent. of body weight.**				
Three hours later.	1054·5	72	5,613,000	30,000	None.	8·4
5	1055	72	5,960,000	10,000	„	...
7	1055	70	6,250,000	20,000	„	...
9	1054·5	72	6,300,000	20,000	„	8·2
11	1057	72	6,140,000	15,000	„	...
14	1057	74	6,413,000	12,000	„	8·4
15		**Blood abstracted, 3·2 per cent. of body weight.**				
16	1052·2	62	5,020,000	28,000	None.	8·4
17	1051·2	56	5,400,000	30,000	Few (10).	...
18	1053	60	5,440,000	14,000	Few (20).	...
19	1053·3	58	4,950,000	14,000	Very few (5).	...
21	1054·5	58	5,090,000	12,000	None.	8·2
22		**Blood abstracted, 3 per cent. of body weight.**				
23	1050·5	48	4,160,000	54,000	Few (10).	8·2
24	1051·2	48	3,640,000	86,000	Numerous (40).	...
25	1051·2	48	4,030,000	30,000	Few (15).	...
26	1051·2	48	4,067,000	16,000	Very few (3).	8·3
28	1051·2	48	4,060,000	8,000	Very few (2).	...
29		The dog was killed with chloroform.				

Poikilocytosis was never seen during this experiment, neither any tendency to invagination of the red blood-corpuscles; and there was very little variation in the size of the red blood-corpuscles at any time.

On the 17*th day*, two days after the second bleeding, nucleated red cells were found in the films for the first time, about ten in each. There were many more deeply stained, non-nucleated red corpuscles with an irregular surface.

On the 18*th day* several large cells were seen in a plain preparation of blood. Their coarsely granular protoplasm had a faintly yellow tint. A somewhat small one (24 μ in diameter) was noticed to have a rounded bud (8 μ) projecting from its surface, the protoplasm of which was markedly yellow. Nucleated red cells were in larger numbers than on the previous day, about twenty in a film. The blood plates were very numerous, and the plain preparations showed a rich fibrin network.

On the 19*th day* there were no large cells found in the blood, and only a few nucleated red cells in the films, about five in each.

On the 21*st day* there were no large cells found and no nucleated red cells, but there were many softer, more deeply stained red blood-corpuscles.

On the 23*rd day*, the first day after the third hæmorrhage, large cells were not found in six plain preparations of blood. A remarkable phenomenon was the very large

number of leucocytes, there being one uninucleated to three multinucleated. About ten nucleated red cells were found in each film.

On the 24th day three or four large cells were found in four preparations. One cell was seen under the microscope on the warm stage about two minutes after it was removed from the body ; in it a coarsely granular core of protoplasm was surrounded by a rim of yellowish finely granular almost hyaline protoplasm, that showed active amœboid movement. In the rim were several rounded projections, four of which were seen to become detached as small round cells. Nucleated red cells are fairly numerous in the films, about forty in each. Their perinuclear protoplasm is in smaller amount than usual and apparently also softer, as the outline of the cell is nearly always irregular, while that of the red corpuscles is regular. Many red corpuscles stain more deeply than the rest, and some only of these have an irregular surface.

On the 25th day one large cell was seen in seven preparations. Nucleated red cells are less numerous than in the films of the previous day ; about fifteen were seen in each film.

On the 26th day two large cells were seen in two preparations of blood, one in each. The one cell measured 26 μ by 11 μ, and from one side of it there projected a nucleated bud, 10 μ in diameter. The whole cell had a yellow tinge. Only two or three nucleated red cells were found in a film.

On the 28th day one or two nucleated red cells were found in each film ; and two plain preparations of blood showed two large cells, somewhat below the average size.

On the 29th day the dog was killed.

The Spleen was $3\frac{1}{2}$ inches in length and weighed 16·7 grammes. It was of a dark red colour, of firm consistence, and was not very vascular. Fresh preparations and films showed several giant cells and a fairly large number of nucleated red cells and erythroblasts ; all these kinds of cells were distinctly more numerous than in similar preparations of the previous spleen. Amœboid movement was not seen in the giant cells, which were examined in aqueous humour on the warm stage.

(Preparations of *the Bone-Marrow* showed numerous giant cells ; but none were seen in films made from *the Lymph Glands.*)

In sections of the Spleen there was seen a comparatively small number of giant cells, on a rough computation about 250 in each. They have the ordinary characters of giant cells in a not very active condition, that is, their nuclei show little budding and there are relatively few mouth-like openings at their surface. The knobs projecting from the central nuclear heap are sometimes seen to be the rounded ends of short thick pyriform buds. Their protoplasm has a well marked yellow tint. There are considerable numbers of erythroblasts and nucleated red cells in the pulp, by no means so many as in the spleens of the three former dogs, but more numerous than in the immediately preceding spleen. There occur in the veins not a few nucleated red cells. The follicles, whose germinal centres are relatively large, contain a considerable number of pigment-holding cells, but there is little pigment in the pulp. Occasionally a protoplasmic knob of a giant cell, and sometimes an erythroblast, has the colour of pigment, due probably to

a post-mortem change. We think it likely that the latter appearances are due to similar causes to those which produce a pigmented zone under the capsule of any spleen that is exposed to the drying influence of the air before hardening.

In *the Bone-Marrow* of the femur there are fairly large numbers of giant cells, perhaps about 120 in a section. But they are by no means so close together as in the spleens of some young Mammals, nor in the spleen of the adult hedgehog. Their average size, too, seems to be rather smaller: one of the largest measured 34 by 20 μ, while the average diameter seems to be about 20 μ. Their characters are apparently identical with those of the cells found in the spleen. There are many small giant cells present whose protoplasm stains faintly blue with hæmatoxylin. Erythroblasts and nucleated red cells occur in large number; their perinuclear protoplasm has a distinctly yellow tinge; their nuclei occasionally show karyokinetic figures,—the nuclei at any rate of the erythroblasts,—as do also the nuclei of the giant cells. There are numerous eosinophilous cells present.

In a *Lymphatic Gland* taken from the neck there are apparently no giant cells, but there are a few erythroblasts and nucleated red cells, and eosinophilous cells, and fairly numerous pigment cells and coarsely granular protoplasmic corpuscles, all contained in the medullary sinuses of the gland.

In *a Mesenteric Lymph Gland* there are a few somewhat small giant cells, whose average diameter is about 20 μ. Their protoplasm is rather finely granular, and stains only faintly pink with eosine. The nuclei are sometimes arranged in a ring, midway between the centre and the periphery of the cell, but sometimes they nearly fill the whole cell. Occasionally the giant cells have vacuoles. Erythroblasts and nucleated red cells are numerous; the perinuclear protoplasm of both stains faintly, if at all, with eosine, and seems to be practically destitute of hæmoglobin. There are a few coarsely granular protoplasmic corpuscles present, some of which are vacuolated, and numerous pigment-holding cells.

Results of Experiments.

It seems, therefore, that upon the induction of the anæmic state in dogs the spleen reverts to its early condition, that characteristic of early extra-uterine life. And the number of giant cells in the spleen appears to vary directly with the number of erythroblasts and nucleated red cells in it, and to some extent with the number of nucleated red cells in the blood; but giant cells may be present in the spleen without any nucleated red cells occurring in the blood of the splenic vein.

In my experiments the spleen was not found to be remarkably swollen, or to have the rose-pink colour described by Bizzozero and Salvioli; but the spleens of Dr Muir's experiments were much more swollen, and it seems probable that those appearances co-exist with the higher degrees only of hæmatopoietic activity.

That many nucleated red blood-corpuscles are found in the red bone-marrow, and

comparatively few in a similar mass of the splenic pulp, seems to me to be insufficient ground for concluding that blood formation is more active in the former than in the latter, for the cells of the pulp in all probability reach the blood stream much more easily and rapidly than do those of the marrow; the spleen has a very large and free blood supply, while the bone-marrow has a comparatively poor blood supply; the splenic pulp is surrounded by a contractile and elastic framework, but the red marrow is inclosed in a rigid case of bone; the spleen undergoes rhythmic contraction every minute and periodic enlargement during digestion, when the spaces of the pulp may be thoroughly flushed out, but, as far as we know, no such change affects the bone-marrow.

Summary of Effects of Hæmorrhage.

The following are the principal changes that were observed in our experiments as a consequence of the abstraction of blood:—

A. *On the Blood:—*

(1) A fall in the number of red corpuscles.
(2) A fall in the specific gravity.
(3) A fall in the percentage of hæmoglobin.
(4) An immediate and transient increase in the number of leucocytes.
(5) A late diminution in the average size of the red corpuscles.
(6) A transient appearance of giant cells.
(7) A transient appearance of nucleated red cells.
(8) An increase in the number of blood plates.

B. *On the Spleen:—*

(1) A slight increase in size.
(2) The appearance of numerous giant cells.
(3) The appearance of proportionately numerous erythroblasts and nucleated red cells.

The latter two facts afford, we think, strong positive evidence in favour of the view that the presence of giant cells is a frequent, if not an invariable, accompaniment of blood formation; and, together with the phenomena exhibited by the giant cells of the blood on the warm stage, strongly suggest the probability that the giant cells produce erythroblasts in the spleen.

On Artificial Anæmia in the Rabbit.

But I have some negative evidence to offer, derived from the examination of *the spleen of an anæmic rabbit.*

Both Neumann and Freyer * and Bizzozero and Salvioli † found that, in rabbits,

* Neumann (29), p. 446.

† Bizzozero (30), p. 599.

artificial anæmia does not stimulate the spleen to hæmatopoietic activity. MUIR * produced anæmia in two rabbits with similar results. One rabbit was bled to the extent of 2·2 per cent. of the body weight; the red corpuscles fell as low as 2,846,000 from 6,181,000; but nucleated red cells did not appear in the blood, nor did he find any in the spleen on examining it in the fresh condition. He was good enough to give me the spleen for examination.

Each *Section of the Spleen* shows a portion of one or sometimes of two giant cells. Erythroblasts and nucleated red cells are present in very small numbers. The follicles contain many leucoblasts, and there are numerous small lymphoid cells or uninucleated leucocytes in the pulp. Fairly large numbers of coarsely granular protoplasmic corpuscles, some of which are vacuolated, are found in the pulp, and a few in the follicles. Numerous pigment-holding cells occur both in the follicles and pulp, and large masses of coarse granules are present in the splenic veins.

These facts tend to show that, if blood formation in the spleen does not follow the production of artificial anæmia, the giant cells do not appear in it in any considerable numbers, and that, with few erythroblasts and nucleated red cells in the spleen, there are very few giant cells present in it.

And the occurrence of giant cells in large numbers in the spleen of dogs rendered anæmic, and of young animals actively forming blood, cannot, I consider, be explained on the theory that the giant cells are phagocytes; while the fact that I have never found red blood-corpuscles within the giant cells is to me negative evidence strongly against that theory.

PART III.

METHODS—BIBLIOGRAPHY—DESCRIPTION OF FIGURES.

CHAPTER VI.

Methods.

The spleens were invariably obtained as fresh as possible.

Of the three principal methods of hardening employed, that of the Physiological Laboratory of the University of Edinburgh has given, on the whole, the best results. Small portions of the spleen are placed in methylated spirit for twenty-four hours, then in a mixture of MÜLLER'S fluid and methylated spirit (in the proportion of three of the former to one of the latter by volume); the fluid is changed on the fourteenth day; on the twenty-ninth day the tissue is transferred to methylated spirit, previously washed well in water to remove the bichromate salt, and after a fortnight in alcohol the tissue is ready for section. FLEMMING'S strong solution (chrom-osmic-acetic acid), followed by alcohol, gave very good results, but his weak solution produced alteration in some of the

* MUIR (47), p. 497.

cellular elements. The method of fixing the tissue by a saturated solution of corrosive sublimate proved to be very good for the spleen. The solution was sometimes used warm, and sometimes 0·75 per cent. sodium chloride was added. Small pieces of tissue were placed in this solution for about half-an-hour, after which they were thoroughly washed in water, normal salt solution, or dilute alcohol, and were then taken through successive alcohols of increasing strength, and left in methylated spirit until sufficiently hardened.

Sections were made in two ways—after freezing the tissue saturated with gum and after imbedding in paraffin. Each was found to be preferable for different purposes; in studying the cellular elements of the pulp, the giant cells were best shown by the gum method, and the erythroblasts by the paraffin method. The former was of special service in allowing of the detachment of the cellular elements of the pulp from the reticulum. We found the gum method the more generally preferable. The method of "shaking" the sections was found to be better than that of pencilling them, because it was practically impossible to remove the free cells without removing large portions of the stroma as well. Sections previously stained were placed in a wide test tube with water or normal salt solution, and the tube was gently shaken for about a minute. The sections were always broken up into several pieces of varying size, and this was advantageous, as the reticulum was revealed best near the free edges of such small pieces.

In staining the sections, no method proved so valuable as that of using hæmatoxylin followed by eosine. Sections were placed in a solution of the former, in the strength of one to twenty of distilled water, for about ten minutes; they were then washed in distilled water and allowed to remain in a 1 in 2000 watery solution of eosine for two or three minutes. The eosine was of special use in acting as an energetic stain for protoplasm containing hæmoglobin. Picric acid in saturated alcoholic solution was sometimes used instead of eosine. EHRLICH'S acid hæmatoxylin gave good results. EHRLICH-BIONDI'S triple stain, of methyl green, acid fuchsine, and orange, was occasionally used, but was of no special advantage. The sections were sometimes mounted in FARRANT'S solution, but generally in Canada balsam.

The splenic tissue was often examined in the fresh state, sometimes in the form of a simple scraping, but usually diluted with a normal salt solution tinted by methyl blue. Portions of scrapings diluted with aqueous humour or hydrocele fluid were placed between cover glasses, rung with oil and examined on SCHÄFER'S warm stage. Films were made by drawing cover glasses over the cut surface of the spleen, and then either dried in the air and stained with alcoholic solution of methyl blue, or, what we found much better, on Dr MUIR'S suggestion, fixed by a warm saturated solution of corrosive sublimate for half-an-hour, taken through successive alcohols, stained with EHRLICH'S acid hæmatoxylin, and subsequently, in some instances, with alcoholic solution of eosine. The surplus hæmatoxylin was removed by washing in acid alcohol, and the films were cleared with clove oil before they were mounted in balsam. The blood films, after being dried in the air for not less than twenty-four hours, were stained

with a saturated alcoholic solution of methyl blue, and sometimes also with a weak alcoholic solution of fuchsine; they were washed in water, allowed to dry, and mounted in balsam.

It is now my pleasant duty to express my thanks to those who have so kindly helped me in my research, more especially to Professor RUTHERFORD, for the constant interest he has shown in my work, for many valuable suggestions, for much patient advice, and for the generous manner in which he placed at my disposal the resources of his laboratory; also to Sir WILLIAM TURNER, to Professor HAYCRAFT of Cardiff, to Dr SIMS WOODHEAD of the Laboratory of the Conjoint Colleges, to Dr CARLIER and Dr MUIR of the University of Edinburgh, to Dr RAIMES of York, and to Mr GRAY, formerly of the Laboratory of the Royal College of Physicians in Edinburgh.

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DESCRIPTION OF FIGURES.

Plate I.

Fig. 1. Hilar sheath in spleen of cat × 50. 1. Muscular layer. 2. Connective tissue layer. 3. Artery. 4. Vein. 5. Nerve.

Fig. 2. Hilar sheath in spleen of hedgehog × 60. 1. Muscular layer. 2. Connective tissue layer. 3. Artery. 4. Adenoid sheath. 5. Follicle.

Fig. 3. Follicle in spleen of rook ($\frac{1}{10}$th inch Beck, water-immersion). 1. Arteries. 2. Capillary. 3. Lymphoid cells. 4. Large cells in follicle. 5. Large cells in pulp. 6. Peripheral muscular layer.

Fig. 4. Follicle in spleen of hedgehog × 300. (Upper portion of fig. 2, more highly magnified.) 1. Artery. 2. Hilar sheath. 3. Lymphoid cells of follicle. 4. Peripheral muscular layer continuous with hilar sheath. 5. Adenoid sheath. 6. Cells of pulp.

Plate II.

Fig. 5. Ellipsoid in spleen of ox ($\frac{1}{10}$th inch Beck, water-immersion). 1. Axial vessel. 2. Ground substance with lymphoid cells. 3. Peripheral layer of spindle cells. 4. Microscopic trabeculæ. 5. Cells of pulp.

Fig. 6. Ellipsoid in spleen of dog × 350. 1. Entering artery. 2. Axial vessel. 3. Emergent vessels. 4. Capillary channels. 5. Lymphoid cells in ground substance. 6. Surrounding blood-sinus. 7. Cells of pulp.

Fig. 7. Reticulum of pulp in spleen of dog × 350. 1. Cells of reticulum. 2. Lymphoid cells. 3. Protoplasmic corpuscles.

Fig. 8. Reticulum of pulp in spleen of frog with cells containing pigment × 300.

Fig. 9. Cells of pulp in spleen of tortoise (Zeiss, E.). 1. Giant cells. 2. Protoplasmic corpuscle. 3. Lymphoid cells.

Figs. 10 & 11. Giant cells and erythroblasts in pulp of spleen of young pig (Zeiss, E.).

Fig. 12. Giant cell in pulp of spleen of puppy (Zeiss, E.). 1. Erythroblast apparently within giant cell. 2. Erythroblasts around giant cell. 3. Lymphoid cells.

Plate III.

Fig. 13. Uninucleated vacuolated cell in pulp of spleen of half-grown rat (Zeiss, E.).

Fig. 14. Uninucleated vacuolated cells in pulp of spleen of guinea-pig (Zeiss, E.).

Fig. 15. Giant cell in spleen of an eight months' human fœtus (Zeiss, E.). 1. Giant cell, with pyriform nuclei, vacuoles, and mouth-like openings. 2. Erythroblasts. 3. Lymphoid cells. 4. Red blood-corpuscles.

Fig. 16. Cells of pulp in spleen of an eight months' human fœtus (Zeiss, E.). 1. Venule. 2. Special multinucleated vacuolated cell. 3. Young giant cell. 4. Erythroblasts. 5. Red blood-corpuscles. 6. Spindle-shaped fibres, apparently muscular, in wall of vein, some cut obliquely, others transversely.

Fig. 17. Special multinucleated vacuolated cell in same spleen, showing numerous empty vacuoles (Zeiss, E.).

Fig. 18. Special cell in spleen of child, showing an erythroblast within a vacuole (Zeiss, E.).

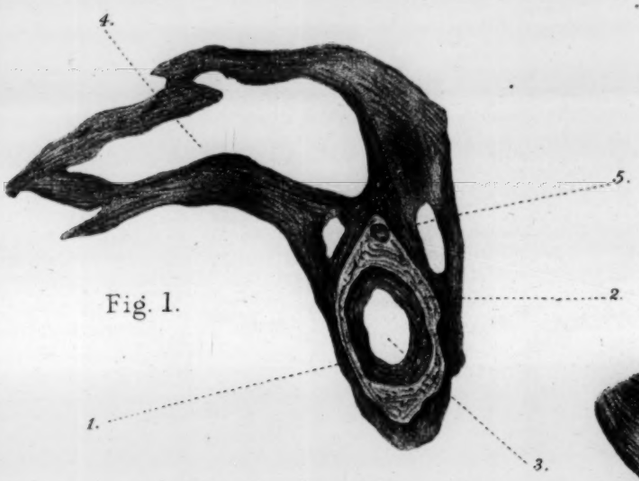
Figs. 19 & 20. Special cells in spleen of child (Zeiss, E.).

Fig. 21. Giant cell in spleen of child (Zeiss, E.).

Fig. 22. Giant cell with budding nucleus in spleen from case of leucocythæmia (Zeiss, E.).

Fig. 23. Giant cell in spleen of anæmic dog (Zeiss, E.).

Dr Whiting on the Comparative Histology of the Spleen — Plate 1.



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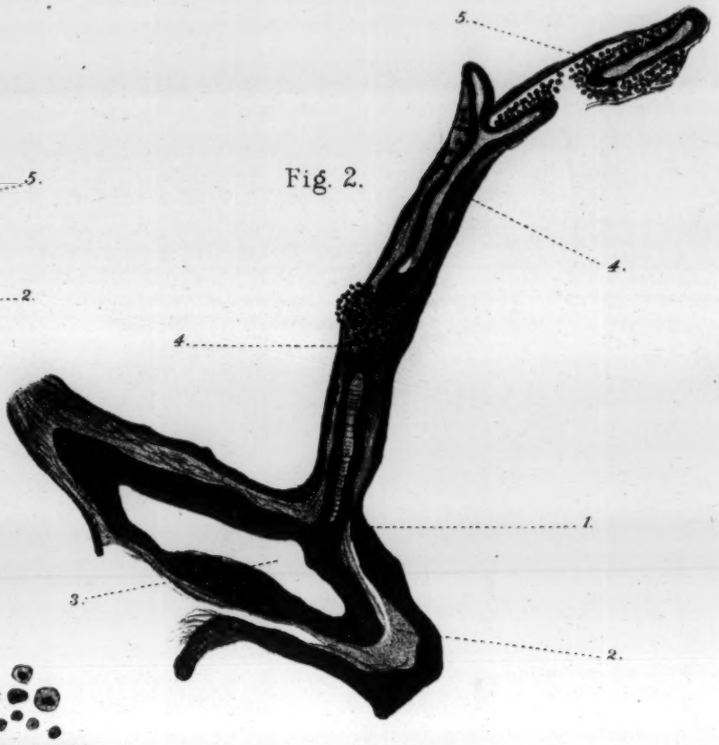

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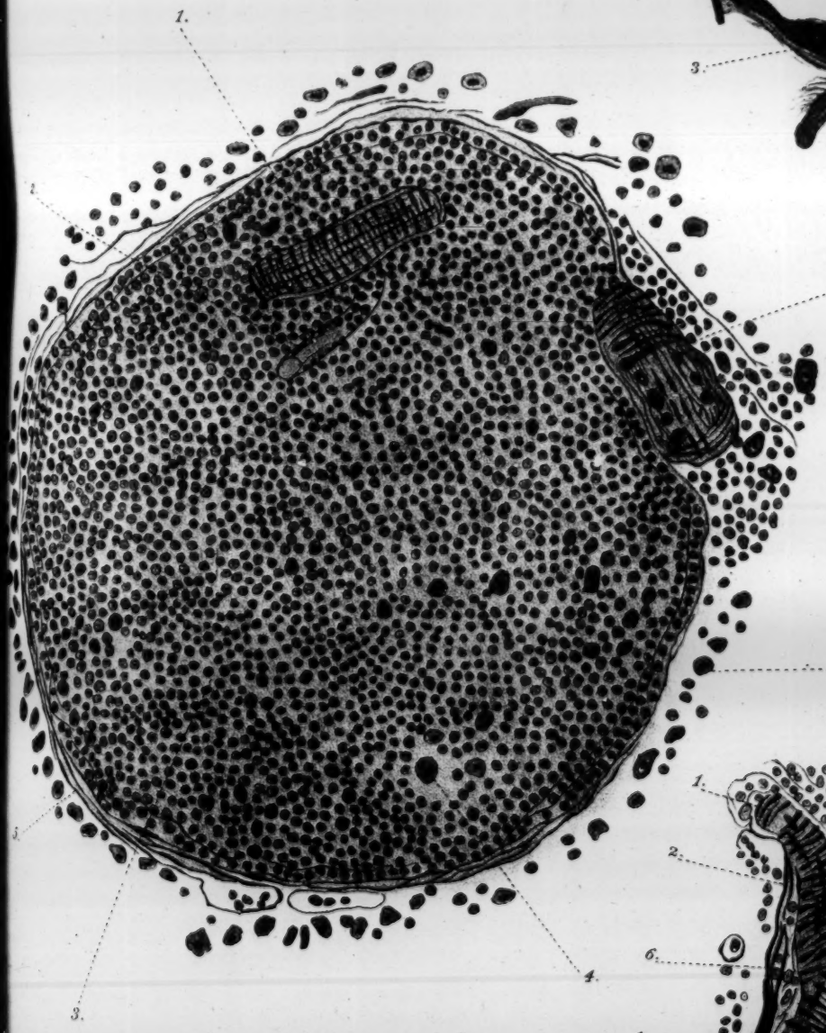

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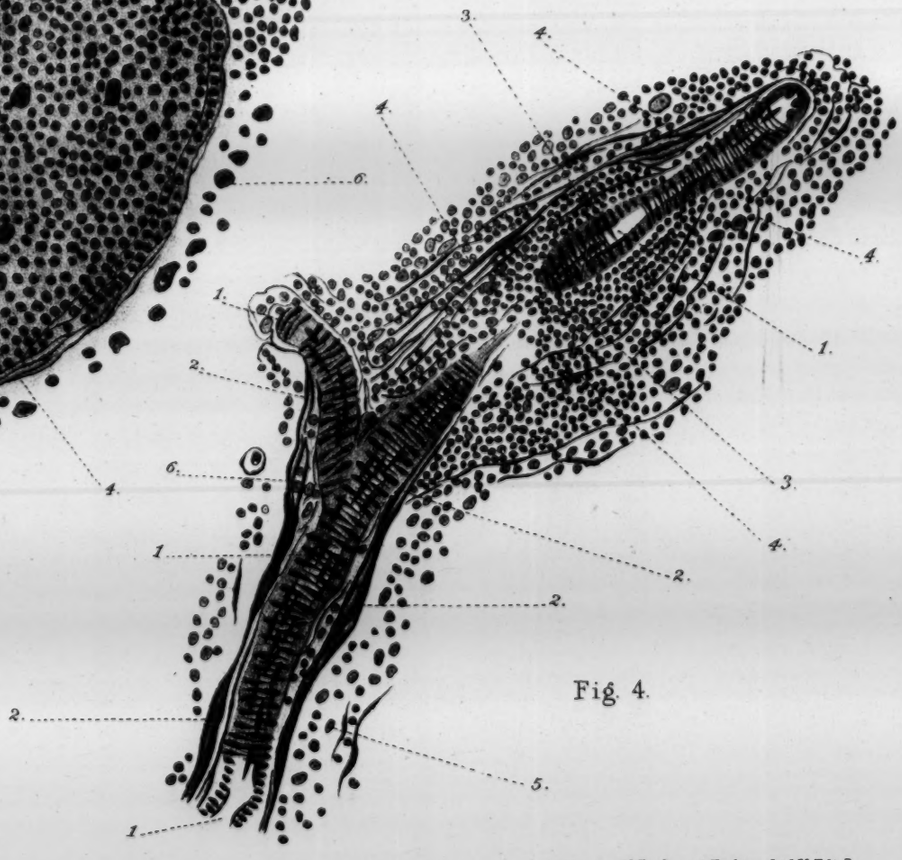

Fig. 4.

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Dr. Whiting on the Comparative Histology of the Spleen — Plate II.

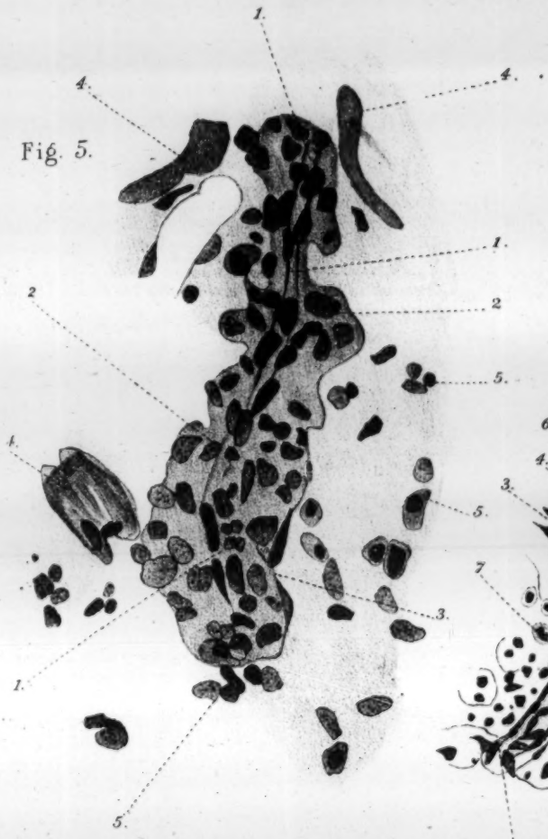
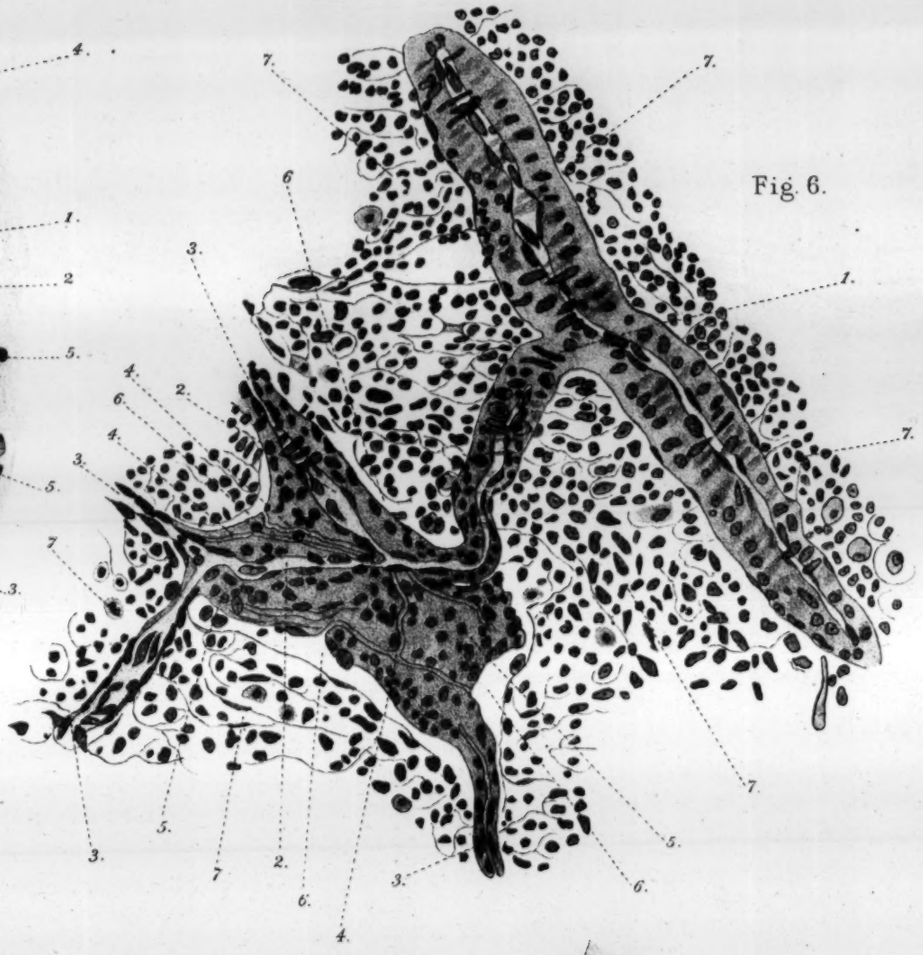


Fig. 5.



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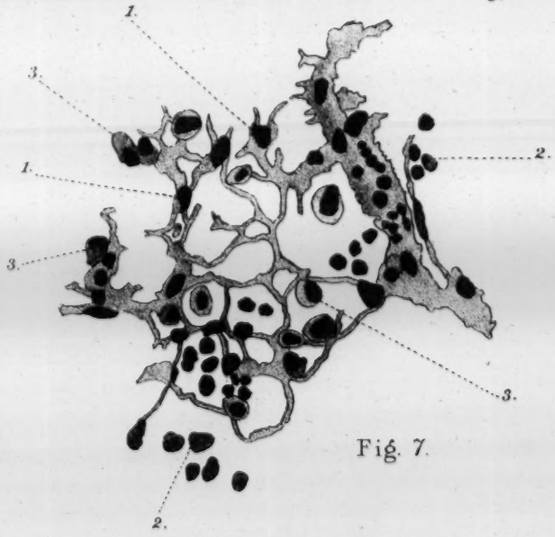

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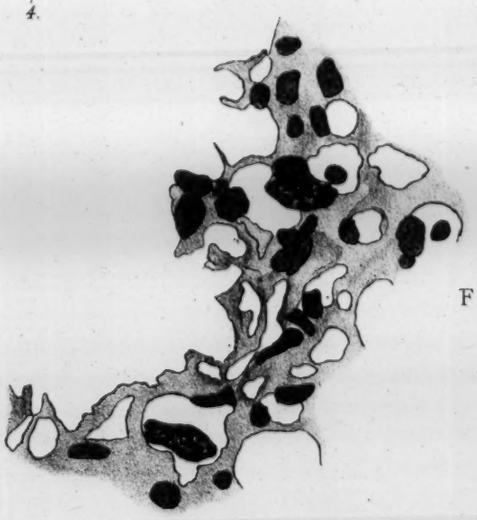

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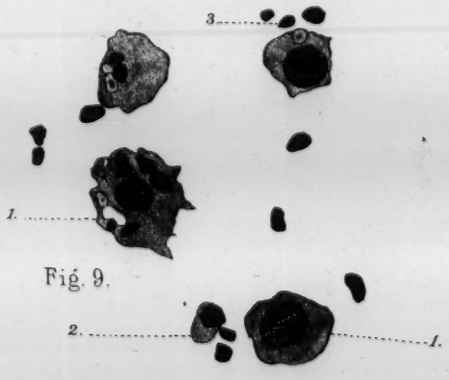

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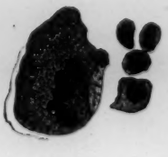

Fig. 10.

Fig. 11.

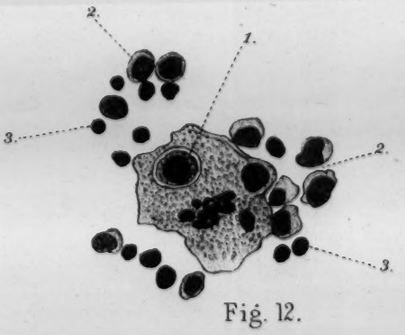

Fig. 12.

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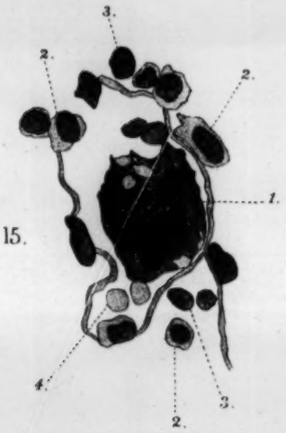
Dr Whiting on the Comparative Histology of the Spleen — Plate III.

Fig. 13.

Fig. 14.



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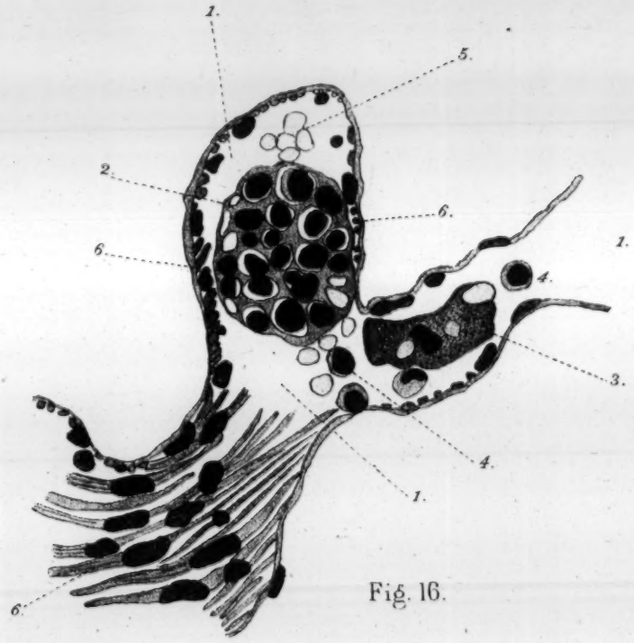

Fig. 16.

Fig. 17.

Fig. 18.

Fig. 19.

Fig. 20.

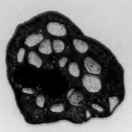

Fig. 21.

Fig. 22.

Fig. 23.

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IX.—*Specific Gravities and Oceanic Circulation.* By Alex. Buchan, M.A., LL.D. (With Maps.)

In the report on Oceanic Circulation, based on the observations made on board H.M.S. "Challenger," and other observations, which was published in the beginning of 1895 as an Appendix in the Summary of Results, Second Part Challenger Reports, the specific gravities dealt with were all at the standard temperature of 60° Fahr., the standard density being that of distilled water at 39°·2 (4° C.). By this method of treatment the question of the salinity or saltness of the water is approximately stated, unquestionably one of the most important questions affecting the physics of the ocean. But the movement of the water, or oceanic circulation, as resulting from different densities, can only be represented by stating, not the specific gravity reduced to the uniform temperature of 60°, but the specific gravity at the observed temperature at all points in the ocean at which observations are made. In this paper these specific gravities are viewed in their relations to the circulation of the waters of the ocean.

In the Challenger Report every effort was made to secure that the maps of mean temperature and mean specific gravity of the surface of the ocean were constructed from annual means, since maps thus constructed are altogether indispensable in any discussion of oceanic circulation. This discussion therefore proceeds from data, representing on a map of the earth the mean annual specific gravity of the surface waters at the mean annual temperatures of the surface. Map 1 represents such a map, which has been constructed in this way:—A table of mean annual temperature for every 10° of longitude and every 5° of latitude was constructed from the map of surface temperature given in the Challenger Report, and a similar table of mean annual specific gravity at the temperature of 60°.* From these two tables another table was constructed, giving the mean specific gravity at the temperature of the surface for the same points of the ocean, numbering in all 640 points. The mean of these 640 specific gravities is 1·0252, allowance being made for the diminution, with latitude, of the areas of the "squares." Each of the specific gravities was then compared with this general average, the difference entered in its place on the map, and the lines of differences—0·0010, 0·0020, and 0·0030, &c., above and below the average—were thereafter drawn on the map.†

None of the observations on board the "Vitiaz" were made at greater depths than 800 mètres or 437 fathoms; and those on board the "Gazelle" only at the surface, at depths of 50 and 100 fathoms, and at the bottom of the ocean. Hence the observations on board these ships are unfortunately seriously defective as aids in discussing the problem of oceanic circulation. A considerable number of observations, such as those

* Report, Maps 1 and 2.

† For sources of information from which the specific gravities have been obtained, see Appendix, p. 342.

observed on board the "Novara," could not be utilised, since the temperature of the sub-surface water was not recorded along with the specific gravities.

An examination of the observations which are available shows that the number is sufficient to represent important sections of the ocean only at depths of 100, 200, 300, 400, 800, and from 1500 fathoms to the bottom, Maps 2 to 8; the number at other depths are altogether insufficient to represent any considerable portion of the ocean which could cast additional light on oceanic circulation. Thus, at 500 fathoms there are only 11 observations; only 6 at 600 fathoms; and even at 1000 fathoms the number is only 7. Hence it is impossible yet to attempt to represent the specific gravity of the ocean at any other depths than those dealt with, even over comparatively limited areas.

Since in constructing Map 1 the data employed are fairly good annual means, the mean specific gravity of the surface of the ocean may be represented by coloured shadings of red and blue, according as above or below the mean specific gravity of all the oceans taken together, or 1·0252. But, as regards all the other maps, the observations are too few, and, with reference to the different expeditions, are necessarily disposed in lines and not in a scattered manner over the different oceans traversed. It has therefore been judged expedient to represent the results not by lines, but only the actual observations themselves. These are given in the form of differences from the simple mean of the whole observations made at the depth represented by each map. When the differences are above this mean the figures are red, but when under it they are blue. Thus, at 100 fathoms the mean of all the observations is 1·0261; if, then, 14 in red ink is entered on the map at any point, the specific gravity there is 1·0275; but if it is entered as 17 in black ink, then it is 1·0244. In this way the maps represent the actual state of our knowledge at present; and what is of the utmost importance, they show us in a most impressive manner the enormous tracts of the ocean for which we have absolutely no observations—in other words, of which we possess no real knowledge.

The following are the more important of these enormous blanks in the ocean at depths of 100 fathoms and lower:—The whole of the North Atlantic between long. 10° and 60 °W. to the north of lat. 40° N. is not represented by a single observation—a state of matters not creditable to this country. For some considerable distance to the east of the United States, the whole of the Gulf of Mexico, the Caribbean Sea, and an immense region to the south-east, from lat. 20° N. to South America, as far to eastward as long. 30° W.—a region whose importance in this inquiry it is impossible to over-estimate—are enormous blanks, not creditable to the Governments of the United States, Great Britain, and Brazil. If we except the observations of the "Gazelle" at 100 fathoms and at the bottom, and Admiral Makaroff's down to 437 fathoms, the whole of the Indian Ocean presents an unrelieved blank, an ocean so very important in the inquiry, seeing that it is a closed ocean north of lat. 25° N. The Pacific Ocean is unrepresented to the north of lat. 40° N. and east of long. 170° E., and also to the east of a line drawn from about lat. 35° N. and long. 155° W. to lat. 30° S. and long. 130° W. Except

the "Challenger" observations and a few made by the "Gazelle" near South America, the Great Southern Ocean is without observations to the south of about lat. 45° S.; and, as regards this region, no other part of the ocean of equal influence and importance can be named as ruling oceanic circulation.

The following is a list of the maps* :—

Map 1.—Mean Annual Specific Gravity of the Surface of the Ocean at Temperature of Observation.

Map 2.—Specific Gravity at Observed Temperature at depth of 100 fathoms.

Map 3.— Do. do. do. 200 fathoms.

Map 4.— Do. do. do. 300 fathoms.

Map 5.— Do. do. do. 400 fathoms.

Map 6.— Do. do. do. 800 fathoms.

Map 7.— Do. do. from depth of 1500 fathoms, to the bottom.

Map 8.—Specific Gravity of the Ocean $S\left(\frac{60^\circ}{39{\cdot}2}\right)$, at depth of 100 fathoms.

Map 9.— Do. do. depth of 1500 fathoms to the bottom.

The following table shows the mean specific gravity of the ocean deduced, as above described, from all available observations at the various selected depths; first, reduced to the uniform temperature of 60°; and, second, to the observed temperatures of the observations. In calculating these averages, the observations made in "closed areas" were not used; the observations are, however, entered on the maps.

	At 60°.	At Observed Temperatures.
Mean specific at surface, . .	1·0262	1·0252
,, 100 fathoms, .	1·0260	1·0261
,, 200 ,, .	1·0258	1·0268
,, 300 ,, .	1·0257	1·0271
,, 400 ,, .	1·0256	1·0273
,, 800 ,, .	1·0256	1·0276
,, 1500+ ,, .	1·0258	1·0279
,, 2000+ ,, .	1·0258	1·0280

Since the first column, which shows the specific gravities reduced to the uniform temperature of 60°, may be regarded as giving the approximate salinities† of the ocean at the different depths, it is seen that the mean salinity of the ocean is the maximum at the surface,—that it steadily diminishes from 1·0262 to 1·0256 from the surface to 800

* Maps showing specific gravity at $\left(S\frac{60^\circ}{39{\cdot}2}\right)$ were also constructed for depths of 200, 300, 400, and 800 fathoms, which are not produced with this Paper, but are referred to in the text.

† In this paper the term salinity will, for convenience, be employed to represent the specific gravity at 60°.

fathoms at least; but that at 1500, 2000, and greater depths, it increases to 1·0258. With reference to the increased salinities of the ocean at depth of 1500 fathoms and greater depths, it is suggested in the Challenger Report under the heading "The Southern Ocean," pp. 36–38, that it probably has its origin in the relatively high salinity of the surface water of the south portions of the Atlantic, Indian, and Pacific Oceans. These surface waters are driven southwards by the strong west-north-westerly winds till, reaching the region characterised by heavy rainfall and extensive ice-melting, they sink to great depths, bearing their high salinity with them. Future observations, which may more adequately represent the temperature and salinity of the great Southern Ocean through its depths can alone teach us the true state of the circulation of the waters of this part of the ocean.

On the other hand, the actual specific gravities at the observed temperatures of the different depths, which alone determine movement, are essentially different from the above. Here there is a steady increase of specific gravity, with depth from 1·0252 at the surface to 1·0280 at 2000 fathoms and greater depths. It follows from what has been said that this increase of specific gravity with depth is wholly occasioned by the decrease of temperature down to at least 800 fathoms, as shown by the maps of sea temperature given with the Challenger Report on Oceanic Circulation. But, at depths of 1500 and under, the increasing specific gravity is due both to the slowly diminishing temperature and also to the actual increase of the salinity of the ocean at these great depths. It cannot be doubted that the increased salinity at great depths, where the differences of temperature with depth are very small, is an important factor concerned in the distribution over the bed of the ocean of low temperatures, chiefly from the Antarctic and sub-Antarctic regions, and in a less degree, the Arctic and sub-Arctic regions of the globe.

The distribution of the different degrees of salinity of the ocean over its surface is determined by the prevailing winds taken in connection with their relative dryness, the upwelling from lower depths which occurs chiefly along those coasts where the prevailing winds blow from the land seawards, and the amount of the rainfall.

The prevailing winds over the ocean may be best studied in detail by referring to the Challenger Report on Atmospheric Circulation, pp. 48–69, and the Maps 27–52 of that Report, which show the isobaric lines and prevailing winds of the globe for the months and the year. In these maps the general movement of the atmosphere over the different oceans through the months of the year is clearly shown. The outstanding features of the circulation of the atmosphere bearing on this discussion will be conveniently shown by a somewhat detailed examination of the prevailing winds in January and July.

Prevailing Winds in January.—In the North Atlantic, north of lat. 35° N., atmospheric circulation is ruled by the low pressure in the neighbourhood of Iceland taken in connection with the systems of high pressure over Eurasia on the one hand and North America on the other. From this distribution of the mass of the earth's atmosphere it

inevitably follows that over the eastern parts of America the prevailing winds are north-westerly, and over western Europe south-westerly. Hence, the prevailing winds at this season blow the surface waters of the ocean from the American coasts and West Indies across the Atlantic, then northward over its eastern side, and thereafter round the north of Norway and along the north coasts of Siberia. This state of things results, as regards Europe, in the setting in of a strong ocean current, bringing the waters of warmer latitudes to its western shores; and, on the other hand, as regards America, the draining away from its shores of its warmer surface waters; and as this water is necessarily replaced by the upwelling from greater depths, it is therefore of a lower temperature than that removed by the surface currents.

Similarly, the wind system of the North Pacific is ruled by the low pressure in the north of that ocean, resulting in north-westerly winds in the east of Asia and south-westerly and southerly winds in the west of North America. The great dryness and extremely low temperature of these north-westerly winds have the effect of lowering to a still greater degree the temperature of the North Pacific Ocean.

In the southern hemisphere, south of lat. 35° S., there occur no circumscribed regions of low pressure, but, instead, a broad ring, in width about 30° of latitude, of very low pressure, passes completely round the globe, falling to a mean pressure of about 29·000 inches near latitude 63° S. Over this broad space of low pressure the prevailing winds are strong and approximately westerly or north-westerly all the year round. These strong north-westers, which blow in upon the Southern Ocean by the surface currents they originate and maintain, inconceivably enormous volumes of water from lower latitudes, and these waters moreover of a comparatively high temperature and salinity. These warm and specifically heavy waters, on advancing in their passage southward to those parts of the Southern Ocean where the surface temperature and salinity are low owing to the heavy rainfall, icebergs and melted snow, sink to greater depths and thus become overlaid by the specifically light waters of the Antarctic region, as suggested by Dr Murray.* A marked feature of the waters of the Southern Ocean is the interdigitation of currents differing widely from each other both in temperature and salinity, the colder of these currents having their origin, no doubt, in the numerous icebergs of these regions. An important part played by these vast currents of warm and specifically heavy water, is to mitigate very materially the cold of Antarctic regions, particularly at great depths, and thus confine the ice-clad area to its present limits.

At this time of the year restricted systems of low atmospheric pressure are not to be seen over the ocean, but over the land of the Southern Hemisphere. Of such systems there are these three :—In Australia, South Africa, and South America. The best defined of these systems is Australia, where on all coasts winds blow from the sea upon the land, under whose influence the surface currents of the ocean are directed towards the land.

Prevailing Winds in July.—In this season the geographical distribution of pressure is

* "The Renewal of Antarctic Exploration." By John Murray, Ph.D., LL.D., of the Challenger Expedition (*Geogr Journ.*, vol. iii. p. 18, 1894.)

exactly the reverse in Australia of what obtains in January. Everywhere it increases on advancing from the coast into inland regions. The lowest pressure, about 30·000 inches, occurs near the north coast, and the highest 30·180 inches, over the basin of the Murray River and its affluents. From this region the diminution of pressure continues uninterruptedly northward as far as the summer low pressure system of Asia. Hence, the prevailing winds of Australia are essentially an outflow from the high pressure region of the interior towards the lower pressures of the coasts, particularly the north coast; and the winds are therefore S.E. on the north coast, S.W. at Brisbane, W.N.W. at Sydney, N. at Melbourne, and N.E. at Adelaide.

The high pressure of the south of Australia is continued westwards in the same latitudes through the Indian Ocean. From these latitudes pressure falls continuously northwards to the low pressure area in Asia; and, as the inevitable consequence of that diminution of pressure, southerly winds sweep across that ocean home into Asia. Where they reach the coast after having traversed a great extent of ocean, such as the coasts of India and Burmah, they precipitate a very heavy rainfall, which, from the serious lowering of the specific gravity thus occasioned, has a most retarding effect on the downward circulation of the ocean there. On the other hand, on the northern and western division of the Arabian Sea the rainfall is excessively small, since the winds there have traversed but a small breadth of the ocean; and, consequently, from the dryness of these winds the salinity is much increased, and the vertical circulation becomes thereby greatly accelerated.

Similarly, as pressure diminishes from about lat. 25° S. in the Pacific uninterruptedly to the low pressure of Asia, the prevailing summer winds on the south-eastern coasts of Asia, after having traversed a wide extent of ocean, pour a very heavy rainfall on these coasts and outlying islands, thus very greatly lowering the specific gravity of the surface during these months.

The summer winds of Europe are determined by the high pressure of the Atlantic in its relation to the low pressure systems of Asia and Africa at this time of the year. On the coasts of Spain and North-West Africa the prevailing winds are northerly; farther to the north, on the coasts of France and the British Islands, south-westerly; and on the coasts of Norway westerly and north-westerly. The curving of the winds round the anticyclonic region of the North Atlantic, from N.E. off the coast of Africa to E. and S.E., as they near and pass the region of the West Indies, to S. and finally S.W. off the Eastern States of America, has all-important bearings on the circulation of the waters of this ocean.

The centre of lowest pressure in North America is over the States about Utah, from which pressure rises all round, but chiefly to the south-east and west. In accordance with this arrangement of the pressure, the winds blow from the Gulf of Mexico home to the coasts of the States as southerly winds. On the other hand, the winds on the coasts of the Pacific States are N. and N.W. as far north as Vancouver, but over that island and the coasts to northward they are S.W.

From lat. 30° to 63° S., as already explained, pressure diminishes uninterruptedly from 30·150 inches to 29·000 inches over a broad ring going round the whole globe during all seasons of the year. Now, over the whole of this vast space, westerly and north-westerly winds sweep as strong winds, subject to little, if any, variation with season. From the enormous quantities of warm water they impel before them into the Southern Ocean they may well be considered as playing the most conspicuous part of all the prevailing winds in the circulation of the waters of the ocean.

As regards the salinity of the surface of the ocean, it is seen (Challenger Report, Map 1) that the broad result is a high salinity in tropical and sub-tropical regions, where temperature and evaporation are high, and where the rainfall is small; and a low salinity, where temperature or evaporation are low and the rainfall large.

In the anti-cyclonic regions of the ocean salinity is large, since out of these regions winds blow in all directions, and the drain thereby caused being compensated by vast descending currents of very dry air, evaporation is necessarily large, thus occasioning a high salinity. Of this the anti-cyclonic region of the North Atlantic, which embraces the Sargasso Sea, is a good illustration.

As already explained, the prevailing winds of the North Atlantic do not blow home to the eastern coasts of the United States, the prevailing winds there being south-westerly, and, consequently, the higher salinity is at some distance seaward from the coast. But, to the south of lat. 40° N., the prevailing winds become more westerly as they advance in their easterly course, and as they near the north-western coast of Africa become north-westerly and then northerly; consequently, they blow home to the coast of the north-west of Africa, and there we find the higher salinities close on the coast.

In the South Atlantic the south-east trades blow home to the coast from Cape St. Roque to the estuary of the La Plata in a manner more direct and unimpeded than any other part of the globe can show; and, consequently, it is off this coast where the highest salinities are anywhere found. For a considerable portion of the year the winds of Western Australia are from the west, blowing out of the anti-cyclonic region of the Indian Ocean. On this coast also a higher salinity prevails close inshore. From Australia to South America the salinity is also high.

The volume and strength of the oceanic current, generated and maintained by the prevailing winds of the North Atlantic, is impressively manifested by the high latitude, about lat. 74° N., reached by the surface salinity of the ocean, 1·0260 and upwards. In the North Pacific the highest latitude reached by this degree of salinity is lat. 36° N. In other words, this salinity is pushed 38° of latitude farther northward in the Atlantic than in the Pacific.

On the other hand, in the tropical parts of the Pacific is an extensive region, stretching in length from Panama to long. 170° E., and in breadth from 15° to 20° of latitude, over which the degree of salinity is a little less than 1·0260. This is a region characterised by light trade winds and extensive upwelling of the water

from lower depths. The salinity is also under 1·0260 in the Gulf of Guinea and East Africa, from about lat. 1° N. to lat. 10° S., these comparatively low salinities being in all probability occasioned by the heavy rainfall characteristic of both these coasts.

But by far the most remarkable region of low salinity, both as regards extent and the very low degree to which it is reduced, is that which extends from India, through the East India Islands, to long. 143° E. Further, it extends across the equator to lat. 9° S., and over no inconsiderable breadth the salinity is less than 1·0250. It is to this extensive region of comparatively brackish water which the prevailing winds drive first northwards and then eastwards across the Pacific that we must look for an explanation of the extraordinarily low salinity of the North Pacific, taken as a whole and at all depths, brought about by this surface current. Indeed, the salinity of this ocean may be regarded as abnormally low compared with the other oceans, but more particularly with the North Atlantic.

Another consideration which has the most vital bearings on the question of oceanic circulation is the position of the line of lowest mean atmospheric pressure in inter-tropical regions, seeing that it is towards this line that the prevailing winds and their attending ocean currents flow.

As regards the Atlantic, through all its breadth and in all seasons, this critical line of lowest pressure is situated to the north of the equator. It follows, therefore, that since the surface currents of the South Atlantic, generated and maintained by the south-east trades, cross the equator, they convey a high temperature and a high salinity into a hemisphere other than that in which they have their origin. The remarkable salinity of the North Atlantic, which is markedly higher than that of any other ocean, has its explanation in the enormous overflowings into it by the surface currents of the South Atlantic, together with the equally remarkable contributions to the salinity at the greater depths from the Mediterranean Sea to be afterwards referred to.

Quite different is it with regard to the Pacific Ocean, where, in its western division, the line of lowest atmospheric pressure is for eight months of the year to the south of the equator, where, accordingly, northerly winds, with their accompanying ocean currents, cross the equator to lat. 15° S., as shown by the current charts in course of preparation by the Meteorological Council.

The result is that the temperature and salinity conditions of these two great oceans are reversed. In the Atlantic the highest temperature and salinity are north of the equator, but in the Pacific to the south of it; and the lowest temperature and salinity are in the Atlantic, south of the equator, but in the Pacific to the north of it.

Another important result of the geographical distribution of atmospheric pressure in the Atlantic and Pacific Oceans respectively is that in the Atlantic the north and the south trades are stronger and more persistent than those of the Pacific, and the interspace between them characterised by calm and light variable winds is therefore much narrower in the Atlantic than in the Pacific. From this it follows that the region of

higher surface temperature and of lower salinity in the Atlantic is comparatively much contracted in width; whereas in the Pacific the breadths occupied are several times greater. It is interesting to note that the lower salinity in the central Atlantic, between the high salinity to the north and south, marks with great distinctness the region between the two trade winds; and special attention is drawn to the circumstance that in this region, from long. 30° W., the salinity constantly diminishes eastward to the head of the Gulf of Guinea, where it falls below 1·0260, being here lower than anywhere else on the west coasts of Europe and Africa, from the English Channel southward to the Cape of Good Hope.

So far as observed, the region of lowest salinity is the Sea of Okhotsk, where the mean is only 1·0240; and the next lowest between Greenland and Spitzbergen, where MOHN gives the low mean specific gravity of 1·0245, and the same is the mean of the six observations made by the "Challenger" at the most southern stations. The salinity is also low on the west and east coast of the southern division of South America, owing to the heavy rainfall in the west and the upwelling along the eastern coast.

But when we come to deal with specific gravities at the observed temperatures of the surface, a widely different result is at once seen (Map 1). The broad result is that the distribution of the specific gravity is the reverse of the salinity, the lowest being now inter-tropical and the highest extra-tropical. The absolutely highest, 1·0277, or 0·0025 above the general mean of all the oceans, occurs in the North Atlantic from about Farö, immediately to the north of the Wyville Thomson Ridge, and thence extends, first, in a north-easterly direction, and then an easterly direction mid-way between the north of Norway and Spitzbergen. The great oceanic current which has this region as its final destination may be considered as starting on its course somewhere between the Sargasso Sea and the north-west coast of Africa, and thence successively over the Atlantic accompanying the north-east trade wind; through the West India Islands, where it gradually assumes a northerly direction; then a north-easterly direction, from Florida towards Spitzbergen; and, finally, an easterly course, in the direction of Nova Zembla. It is thus the oceanic current which runs uninterruptedly by far the longest course of any oceanic current, and, consequently, it is in the latter part of this long course where the specific gravity of the surface waters of the ocean attains a higher degree than observations show to occur anywhere else over the ocean. It is of the utmost importance to note that this high specific gravity is not occasioned, as generally is the case where it occurs, by an abnormally low temperature of the water of the sea. On the contrary, the temperature of the sea is here very greatly higher than is observed anywhere else in such high latitudes. The high specific gravity is mainly the result of the higher salinity of the water. This affords the strongest proof that can be adduced, that the great surface currents of the ocean are caused by the prevailing winds.

The absolutely lowest specific gravity, 1·0222, or 0·0030 under the general mean of

the oceans, is found over the Bay of Bengal, and the western part of the China Sea. Nowhere in inter-tropical regions does the salinity of the ocean fall to so low a point as it does over this extensive region. Now, this is the most extensive region of the globe characterised by an unusually heavy rainfall; and this, eminently so, at all seasons as regards the island-studded portion of the western Pacific. The rainfall of this region began to be pretty exhaustively dealt with by the Dutch about seventeen years ago by the planting of rain-gauges, so that now we are put in possession of good rainfall means from 186 stations. At 99 of these stations the annual rainfall exceeds 100 inches, and at 21 stations it exceeds 150 inches. The largest annual amount at any of the stations is 181 inches, and the smallest 48 inches. During the summer monsoon the rainfall is very heavy over the southern slopes of these islands; but during the other months, when the north-east trade prevails, the rainfall is very heavy over the northern slopes. Thus, at all seasons, the rainfall is heavy. Hence, this abnormally low specific gravity is occasioned by the low salinity of the water, as well as by its high temperature.

Several important conclusions follow. The daily amounts are published in the Annual Reports,* which show that daily falls of 5 inches occur often in many places, and on rarer occasions 12 inches a day are precipitated. From the flooding of the rivers, which is thus an event of very frequent occurrence, the deposits of mud must be very great, far greater, indeed, and of wider extent than occurs anywhere else on the floor of the ocean.

Another consequence is the influence of this wide extended region, characterised by so low a salinity of the surface, over the waters of the North Pacific. Since over this region the specific gravity falls to the minimum anywhere observed in the ocean, the tendency of the surface waters to descend is also at the minimum. Further, since the prevailing winds for a large part of the year blow out of the northern part of this region of low salinity, carrying the surface water with them to north-eastward and to east-north-eastward across the Pacific towards America, water of a comparatively low salinity is spread over this ocean. In all probability this is the origin of the remarkable low salinity of the North Pacific at the surface and at all depths. The map showing the specific gravity at depths exceeding 1500 fathoms, Map 8, is very striking, seeing it is there evident that the largest extent of the ocean characterised by specific gravities under the mean is the North Pacific Ocean. To the south of this region, across the equator, specific gravities, on the other hand, are above the mean; but it is to be remarked that the surface of the sea over this latter region has a high salinity.

It is a striking circumstance that these two wide regions exhibit from the surface to the bottom similar differences in their characteristic salinities, viz., salinities under the mean in the North Pacific, but above the mean in the South Pacific. The specific gravities in the ocean to the east of Australia, from a depth of 300 fathoms to the bottom, show excess over the North Pacific, Maps 4 to 8, from which a circulation of the water of the ocean from the South Pacific northwards may be inferred.

* Regenwaarnemingen in Nederlandsch-Indie. Batavia Landsdrukkerij.

In strong contrast with this region of low specific gravity is the specific gravity of the Arabian Sea. The north-western part of this sea, together with the Red Sea and Persian Gulf, is one of the driest regions of the world; and since winds blow offshore seawards, upwelling sets in there, bringing the cooler water of lower depths to the surface, temperature is lower over the Arabian Sea than elsewhere. Consequently, from the lower temperature thus brought about and the larger evaporation, owing to the prevailing dry winds, the specific gravity is high.

The Red Sea presents some interesting features. From the Monthly Charts of the Red Sea* recently published by the Meteorological Council, the following annual averages of surface temperature and specific gravity have been calculated :—

Red Sea.—Mean Annual Temperature and Specific Gravity of the surface of the Red Sea.

Lat. N.	Long. E.	Temperature.	Specific Gravity.	
			At 60°.	At obs. Temp.
° ′	° ′	°		
29 0	33 0	72·0	1·0313	1·0297
27 0	34 20	76·1	304	281
25 0	35 40	78·4	301	274
23 0	37 0	80·4	299	268
21 0	38 10	82·1	295	262
19 0	39 30	83·4	291	255
17 0	40 40	83·7	288	252
15 0	42 0	83·4	285	249
13 0	43 10	81·9	279	246
12 40	45 0	81·3	276	244
12 45	47 0	81·6	276	243
12 50	49 0	81·4	275	243

Thus, the mean annual temperature of the surface is lowest, 72°·0, a little to south of Suez; from which it gradually rises to the maximum 83°·7, near the centre of the sea to the east of Massaua; falls to 81°·9 near the Strait of Bab-el-Mandeb; and still lower on advancing eastwards into the Arabian Sea. The approximate salinity is the maximum, 1·0313, at the head of the sea near Suez, from which it steadily diminishes step by step to 1·0275 in lat. 12° 50′ N. and long. 49° 0′ E. Thus, the strong inflowing current occasioned by the large evaporation from this sea indicates a salinity of 1·0275 as it passes the Strait of Bab-el-Mandeb, which is equal to the maximum salinity of the North and South Atlantic respectively. But, on advancing northwards, the salinity of the surface rapidly increases till the maximum 1·0313 is reached in lat. 29° 0′ N. and long. 33° 0′ E. This is the highest mean annual salinity occurring anywhere on the globe which is in communication with the open sea.

The following temperatures and specific gravities have been observed in the Red Sea by Admiral MAKAROFF :—

* Meteorological Charts of the Red Sea. Published by the Authority of the Meteorological Council. London, 1895.

	Lat. N.	Long. E.	Depth. Fathoms.	Temperature.	Salinity at 60°.	Specific Gravity at ob. Temp.
Outside Strait of Bab-el-Mandeb,	12° 48′	45° 55′	109	60·3	1·0262	1·0262
			219	58·6	1·0264	1·0266
In Strait of „ „	12 30	43 32	437	53·1	1·0266	1·0273
			109	74·5	1·0281	1·0260
In Red Sea, ...	21 30	38 5	109	71·6	1·0301	1·0284
„	„	„	219	71·2	1·0302	1·0285
„	„	„	328	70·9	1·0301	1·0285
„	26 37	34 35	109	71·2	1·0302	1·0286
„	„	„	219	70·5	1·0303	1·0288
„	„	„	328	70·5	1·0302	1·0287

Thus the salinity of the Red Sea at these two stations near the Strait of Bab-el-Mandeb is substantially the same from 109 to 328 fathoms, and this is virtually the mean annual salinity of the surface from lat. 25° to 27° N.; and probably it is the same at all depths lower than the ridge separating the Red Sea from the Arabian Sea, which is about 200 fathoms.

On the other hand, the specific gravity near Suez is 1·0297, but from this point it steadily diminishes, owing to the decrease of the salinity and the increase of temperature, to 1·0246 in the Strait of Bab-el-Mandeb, and, still further, 1·0243 to the south-east of Aden.

But the most important consideration is the enormous difference between the salinity and specific gravity in the Red Sea itself and in the Arabian Sea adjoining. Thus, while at depth of 109 fathoms the salinity at the above two stations in the Red Sea is 1·0302 and 1·0301, it is 1·0281 in the Strait of Bab-el-Mandeb, and only 1·0262 to the south-east of Aden; but, as regards the specific gravities, the figures are 1·0286 and 1·0284 in the Red Sea; in the strait, 1·0260; and off Aden, 1·0262. It follows that the mean annual salinity of the inflowing surface current is 1·0279 in the strait; but the outflowing under-current at the same place at depth of 109 fathoms is 1·0281, and at a depth of about 200 fathoms, being the depth of the ridge separating the Red Sea from the Arabian Sea, it is in all probability 1·0302. In brief, the mean annual temperature, salinity, and specific gravity of the inflowing surface current and outflowing current at depth of about 200 fathoms are these:—

	Temperature.	Salinity.	Specific Gravity.
Inflowing surface water, . .	82°·0	1·0279	1·0246
Outflowing current over ridge, . .	71·0	1·0302	1·0285
Differences, ...	11·0	0·0023	0·0039

Thus, the Red Sea serves as a reservoir from which a constant current of water of a high salinity and temperature flows into the deeper waters of the Arabian Sea. There is only one observation of the salinity of the Arabian Sea at a depth exceeding 200 fathoms. This was made by Admiral MAKAROFF in lat. 12° 48′ N., and long. 45° 55′ E. at a depth of 437 fathoms, and was 1·0266, which is still a high salinity, being 0·0010 above the average of the whole ocean at this depth.

There have, however, been a comparatively large number of temperatures observed in this part of the ocean at various depths, and as shown by the maps of temperatures published in the Challenger Report the temperature of this part of the Arabian Sea off the Arabian Coast is higher than elsewhere down to at least 1000 fathoms. This outflowing under-current from the Red Sea, after passing the Strait of Bab-el-Mandeb, takes an approximately horizontal direction during the first part of its course, but, as it advances, sinks to greater depths, thus imparting a higher temperature and specific gravity to the deeper waters in the north-west of the Arabian Sea.

But this mode of circulation is exemplified on a more extensive scale by the Mediterranean Sea in its relations to the Atlantic Ocean. To the west of the Strait of Gibraltar the salinity of the surface is a little higher than 1·0270, but it quickly increases in advancing eastward till about long. 10° E. it rises to 1·0280, and over the eastern basin it is 1·0290, showing thus a salinity higher than ever occurs in the open sea, and only exceeded by the confined waters of the northern half of the Red Sea. Thus, the water of the Mediterranean, even on the surface, is much salter than that of the Atlantic, due to the dry climate of the region, where the loss from evaporation is not nearly compensated for by the fresh water additions from the rainfall and by the rivers which empty themselves into its basin.

Carpenter's and subsequent observations and discussions have established the important fact that in the Strait of Gibraltar there are, after allowing for tidal influence, two currents, one superimposed over the other. The upper-current is an inflowing one, carrying with it the surface water of the Atlantic; and the under-current is an outflowing one, carrying out with it into the Atlantic the warmer and denser underlying water of the Mediterranean.

The submarine ridge at the strait separating the deep water of the Atlantic from that of the Mediterranean is not quite 200 fathoms from the surface, and hence all direct communication between the seas is confined within that depth. A little way to the east of the strait the temperature of the Mediterranean at 100 fathoms is about 55°, varying about a degree either way, in all probability according to the mildness or severity of the preceding winter; it increases to 58° to the east of Malta, and rises to a little above 60° in the Levant. At this depth the salinity in the Atlantic to the west of the strait is 1·0267, but to the east of it it rises to 1·0284.

At 200 fathoms east of the strait the temperature is 55°, and on proceeding eastward it rises to 57° about long. 20° E. and to 58° in the Levant. The salinity a little to the west of the strait is 1·0268; a little to the east of it, 1·0287; and in the Levant, 1·0290.

At 300 fathoms and greater depths, the temperature of the western basin is 55°·5, and salinity, 1·0287; and in the eastern basin temperature is 56°·5, and salinity 1·0290, according to the numerous observations of the "Pola" Expeditions in 1890–92. The deep water temperature of the Mediterranean is thus closely approximate to the temperature of the Atlantic adjoining the Strait of Gibraltar at the depth of the ridge separating the two seas, or nearly 200 fathoms, but the salinity is very greatly in excess.

At depths of 100 and 200 fathoms specific gravities and temperatures have been observed in the Mediterranean from long. 6° W. to 10° E. at seven points, giving a mean specific gravity of 1·0290; and at eight places outside the strait in the Atlantic from long. 6° to 20° W., giving a mean specific gravity of 1·0272. At 200 fathoms, a short way to the east of the strait, the specific gravity is 1·0291; in the strait, 1·0282; and a little way to the west, 1·0273, and a short way to west of this point, 1·0267. The strong under current from the Mediterranean to the Atlantic is the inevitable consequence of the extraordinary difference in the specific gravities of the two seas. The inflowing surface current is, of course, due to the lowering of the level of the Mediterranean by the excessive evaporation from its surface. It is therefore not winds and currents, but different specific gravities and different levels, which rule the interchange of the waters of this sea with the Atlantic.

Now, just as in the case of the Red Sea, this dense warm water from the Mediterranean sinks to increasingly greater depths as it advances westward through the Atlantic. This result does not admit of being shown so clearly from the observations of specific gravity, owing, as already stated, to their fewness, as it does by the temperature observations. In the Challenger Report it is well shown by the serial maps of temperature, from which it appears that, owing to the great specific gravity of the warm under-current from the Mediterranean, it gradually sinks on entering the Atlantic; but its effect in heating the waters of this ocean over any considerable extent becomes strikingly apparent at about 500 fathoms. Beyond this depth its influence is felt over nearly the whole breadth of the Atlantic to at least about 1000 fathoms.

The accompanying woodcut, reduced from the Challenger map, shows this in a very impressive manner. The crowding of the lines near the Strait of Gibraltar, the prolongation of some of them across the whole ocean, and the northward movement of the higher isothermals are very instructive.*

It is evident, from what has been already advanced with respect to the influence of the rainfall and the winds, that the salinity of the surface of the different oceans will differ materially from each other. The following are the calculated averages:—

Mean annual salinity of the surface of the			N. Atlantic,	1·0265
,,	,,	,,	S. Atlantic,	1·0265
,,	,,	,,	Indian Ocean,	1·0262
,,	,,	,,	N. Pacific,	1·0257
,,	,,	,,	S. Pacific,	1·0261
,,	,,	,,	All Oceans,	1·0262

* See also Atlantischer Ozean Taf. 3. Deutsche Seewarte, Hamburg, 1882.

Hence the mean salinity of the North and the South Atlantic is the same, and these two oceans have a higher salinity than any of the other oceans. The Indian Ocean comes next with 1·0262; then the South Pacific with 1·0261; and the North Pacific is much lower than any other ocean, occasioned, as above suggested, by the heavy rainfall in its western division and the wide area over which these specifically light waters are carried by the prevailing winds. The mean salinity of the surface of all the oceans combined is 1·0262.

Since observations are greatly more numerous at 100 fathoms depth than at any other depth, a more detailed account will be given of the salinities, Map 8, and specific gravities, Map 2, at this depth. The figures on these maps show, but in a less pronounced manner than at the surface, the essential differences between the geographical distribution of specific gravities and salinities. Since, with increasing depth, temperature

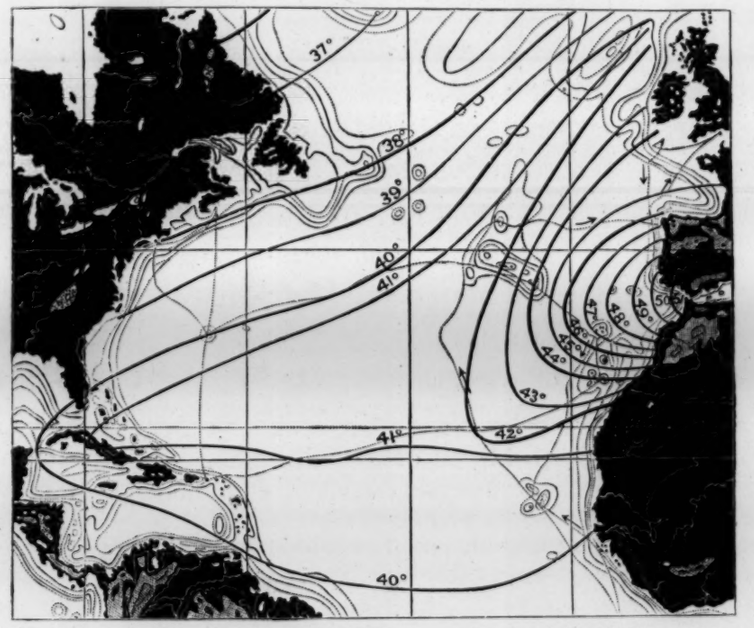


FIG. 1.—Temperature of the Atlantic at depth of 600 fathoms.

continues to approximate closer and closer to equality in all parts of the ocean, it follows that the specific gravities and salinities, as represented by departures from their respective averages, also tend to equality as shown by Maps 7 and 9.

As regards the salinities at 100 fathoms, Map 8, the areas above and below the general average, and the similar areas of the surface of the ocean substantially coincide. Leaving out of view the North Pacific, whose salinity is exceptionally low, the ocean lying between lat. 40° N. and lat. 40° S. has a salinity exceeding the average; whereas all other parts of the ocean fall short of the average. The Red Sea and the Mediterranean have been already dealt with.

The Atlantic stands out as the ocean characterised by the highest salinities. This holds good particularly in those parts towards and over which the prevailing winds blow. The low salinity on the eastern part of the South Atlantic, whence the trade

winds start on their course, forms a striking contrast with the high salinity in its western part, towards which these winds blow. Salinity is also very high off the north-west coast of Africa, towards which the prevailing winds of that part of the North Atlantic are directed. The low salinity in the region of the Doldrums is well marked. Salinity is also under the average in the Indian Ocean, and in the South Pacific from New Guinea and north of Australia as far eastward, at least, as long. 130° W.

On the other hand, salinity is under the average in latitudes higher than 40° north and south, and over all but the whole of the North Pacific, so far as observations have been made. Of all oceans, the North Atlantic shows the highest salinity, and the North Pacific the lowest at 100 fathoms, just as happens on the surface of these oceans, and from like causes. To these regions of low salinity fall to be added a very large portion of the eastern division of the South Pacific, and probably the Gulf of Guinea, but here, at this depth, observations are wanting. The northern parts of the Pacific and the Atlantic offer a strong contrast to each other. Thus, to the north of Japan, the 12 observations within or contiguous to the Sea of Okhotsk, give a mean of 1·0247, or 0·0013 under the average; whereas, in the Atlantic to the north of the Wyville-Thomson Ridge, the mean of the 14 observations is 1·0257, or 0·0003 under the average. The relatively high salinity here is due to the powerful oceanic current flowing thitherward from the low latitudes of the Atlantic. The regions showing the lowest salinity are the Sea of Okhotsk, and round the southern part of South America.

This mode of distribution is substantially reversed on Map 2, showing the specific gravities at the temperature of observation. If the intertropical part of the Pacific, where upwelling from lower depths has been shown to occur, be excepted, the whole of this ocean, between lat. 35° N. to lat. 30° S., exhibits specific gravities under the average, the largest deficiencies being in the western parts of the ocean, where the rainfall is very excessive, and where the temperature of the surface is abnormally high.* Elsewhere, with the probable exception of the Gulf of Guinea, specific gravity is above the average.

By far the largest excess anywhere yet noted in the open sea is in the Arctic Ocean, as determined by Mohn's observations, the mean of the 13 observations made at the greatest depths being 1·0278, or 0·0017 above the general mean of the ocean. The mean of the observations in, or near, the Sea of Okhotsk is only 1·0267, which is a very large difference, when account is taken of the comparatively small range of the observations of specific gravity. The observation of greatest specific gravity made by the "Challenger" was 1·0278 in lat. 62° 26′ S., and long. 95° 44′ E., thus being the same as the mean of the 13 observations in the Arctic Ocean. It is highly probable that an equally high specific gravity characterises the whole of the Antarctic Ocean, and the adjoining portion of the Southern Ocean south of lat. 55°. This high specific gravity of Antarctic and Arctic waters plays an important part in oceanic circulation. The high specific gravity in these oceans, together with the head of water driven forward and accumulated

* Challenger Report, Map 3.

by the strong prevailing south-westerly winds in the Arctic Ocean, and the still stronger prevailing north-westerly winds in the Antarctic Ocean, may be regarded as chiefly supplying the force principally concerned in distributing the ice-cold waters of polar regions over the bottom of the ocean in all latitudes.

Owing to the great blanks in the ocean where no observations have yet been made, it will be convenient to limit the discussion to the following seven regions, which are signalised for well-marked characteristics as regards salinity and specific gravity. The following table shows their positions and salinities and specific gravities, to which is added the approximate means for the ocean taken as a whole, with which they may be compared.

Of these seven areas, the highest salinity occurs in the North Atlantic from lat. 20° to 40°. At the surface and at all depths down to the bottom it exceeds every other ocean in the degree of its salinity. This is caused by the large contributions the surface receives from the South Atlantic by the south trades and attending currents crossing the equator, and by the very large accessions to the salinity contributed to the lower

SALINITIES.

	Pacific Ocean.				Atlantic Ocean.			All Oceans.
	Lat. 0° to 30° N. Long. 118° to 150° E.	Japan to Sandwich Islands.	Sandwich Islands to Equator.	Lat. 0° to 30° S. Long. 150° W. to Australia.	Gulf of Guinea.	Lat. 20° to 40° N. Long. 10° to 70° W.	Lat. 0° to 30° S. Long. 10° W. to America.	
Surface,	1·0257	1·0257	1·0259	1·0266	1·0259	1·0273	1·0272	1·0262
100 fathoms,	257	256	258	266	261	271	266	260
200 „	257	253	256	261	256	269	260	258
300 „	255	253	255	259	255	267	259	257
400 „	255	253	256	259	255	265	259	256
800 „	...	254	256	259	257	266	258	256
1500 „ to bottom,	257	254	255	261	256	266	262	258

SPECIFIC GRAVITIES.

Surface	1·0231	1·0248	1·0231	1·0239	1·0235	1·0256	1·0251	1·0252
100 fathoms,	251	260	261	252	260	269	268	261
200 „	264	266	268	269	269	271	271	268
300 „	269	269	270	272	272	274	274	271
400 „	271	271	272	275	274	278	277	273
800 „	...	274	276	278	275	283	277	276
1500 „ to bottom,	277	277	278	281	277	286	281	279
2000 „ „ „	278	277	278	281	277	286	282	280

depths from the Mediterranean Sea. A striking contrast in salinity is seen in the two portions of the North and South Atlantic respectively. Thus, while in the North Atlantic the salinities at the surface, 100 fathoms, and 200 fathoms are 1·0273, 1·0271, and 1·0269, in the South Atlantic they are 1·0272, 1·0266, and 1·0260; so that through this depth the salinity is reduced three times more in the South Atlantic as compared with the North Atlantic. On the other hand, in the Gulf of Guinea the salinity is at the surface and at all depths less than in the North and the South Atlantic areas, owing to the heavy rainfall in this part of the ocean and lands adjoining and the east flowing current in this part of the equatorial region of the Atlantic.

In the Pacific by far the greatest salinity at the surface and, as in the above cases, through all depths to the bottom is to the east of Australia, whither the surface currents are propelled by the trade winds. It may be noted that the distribution of salinity in this region of the Pacific from 200 fathoms to the bottom is all but identical with that of the region in the South Atlantic. The area of lowest salinity is the region lying between Japan and the Sandwich Islands, which is further characterised as the region of lowest salinity of all the oceans exclusive of the higher latitudes. And this lower salinity is also carried down through all depths to the bottom of the ocean, as shown by the six Maps of Salinities.

The following are the salinities and specific gravities in three regions in the higher latitudes :—

SALINITIES.

	Southern Ocean.		Arctic Ocean.
	Lat. 30° to 55° S. Long. 53° to 133° W.	Lat. 40° to 65° S. Long. 80° to 140° E.	North of Wyville-Thomson Ridge.
Surface,	1·0255	1·0255	1·0258
100 fathoms,	253	254	258
200 „	253	255	259
300 „	253	255	257
400 „	253	255	259
800 „	255	...	...
1500 „	254	255	258

SPECIFIC GRAVITIES.

Surface,	1·0263	1·0270	1·0274
100 fathoms,	266	271	277
200 „	267	273	278
300 „	270	273	...
400 „	271	274	281
800 „	275	...	281
1500 „	277	277	281
2000 „	278	278	...

The striking feature as regards these salinities of the higher latitudes is the much higher salinity of the northern part of the Atlantic and its continuation northward and then eastward through the Arctic Ocean. The high salinity of the surface has been already referred to the prevailing south-westerly winds of the North Atlantic and the strong ocean current which accompanies them. In this case, again, the high salinity prevails not only at the surface, but at all depths down to the bottom of the ocean.

Emphasis is laid on the fact that in each of these areas the relatively high or low salinity of the surface waters is continued uninterruptedly downwards through all depths to the bottom of the ocean.* In this connection, Map 8, showing the salinities at 100 fathoms, may be compared with Map 7, which shows the specific gravities at the bottom of the ocean, the differences being virtually the same as the salinities at these depths, and observations are greatly more numerous at these than at the other depths. This points to the conclusion that by means of the vertical movements of the water there is a vital connection maintained between the surface and the bottom of the ocean, it being plain that, if there be no such connection, the water occupying the deeper parts of the ocean would, through the diffusion of the salt, show a salinity virtually the same everywhere.

Viewed broadly it is seen that salinity is low in the high latitudes and high in inter-tropical regions. But the geographical distribution of the specific gravities is the reverse of this (Map 1), the difference being the simple result of differences of temperature. So far as the water of the sea itself is concerned, or viewed apart from the winds, it is not the salinity but the specific gravity at the temperature of observation that originate and maintain movement in the ocean.

In Map 1, giving the specific gravity of the surface, the red colouring shows those regions where the specific gravity is above the general average of the ocean. It being there where the specific gravity is large, the downward movement of the water is also large, and the deeper the red the downward tendency is the greater. The absolutely greatest is in the Arctic Ocean, between Iceland and the north of Norway. On the other hand, the shadings of blue indicate those regions where the specific gravity is low, and the deeper the tint the lower is the specific gravity. The absolutely lowest is in the Bay of Bengal and the offshoots of the Chinese Sea to the west.

In the Atlantic it is only in the Gulf of Guinea where the specific gravity falls so low as 0·0020 below the general mean of the ocean, the low specific gravity here being caused by heavy rains. In the interval between the north and south trade winds it does not elsewhere fall to 0·0020 below the mean of the ocean, thus forming a marked contrast to the much lower and widespread low specific gravity of the Pacific. This great difference is due to the less breadth occupied by the trade winds with their attendant currents in the Atlantic as compared with the Pacific, the greater strength of the Atlantic trades and currents, and the diversion of this system of winds and currents

* See Mr J. Y. Buchanan's Papers, *Proc. Roy. Soc.*, vol. xxiii. p. 123, and *Proc. Roy. Geog. Soc.*, December 1886, where this peculiarity is shown to hold good from the surface to 200 fathoms.

when they pass the West Indies into the great south-westerly aerial and north-easterly ocean currents of the Atlantic. The effect of this is a drain of no inconsiderable body of the water of the Atlantic from intertropical into extratropical regions.

Another important consideration is that, in the Atlantic to the north of lat. 30° N. and to the south of lat. 30° S., the prevailing winds and the powerful ocean currents accompanying them are directed into higher latitudes. The intertropical portion of the Atlantic has therefore its surface more or less lowered by the north-easterly currents of the North and the south-easterly currents of the South Atlantic. Further, the currents propelled polewards by these great wind systems must more or less raise the level of the ocean in the higher latitudes towards which they blow.

But evaporation and the rainfall tend still further to accentuate these differences of level. If the intertropical part of this ocean be considered by itself, the evaporation is very greatly in excess of the precipitation, and, consequently, the level of this part of the ocean is still further lowered. Over by far the larger portion of the regions swept by the trade winds the loss from the excess of evaporation is about 7 feet per annum. On the other hand, on advancing from the tropics to higher latitudes the evaporation and precipitation tend to approximate, and ultimately the rainfall exceeds the evaporation and very greatly so in high latitudes. Thus, the level of the ocean in these regions is still further increased. If the powerful ocean current poured southward out of the South Atlantic, the large snow and rainfall, and the widespread melting of ice be considered, it is evident that the Southern Ocean to the south of the Atlantic will have its level raised more than any other ocean from these causes. The result will be first a more decided downward movement of its waters, and, as regards the greater depths, an approximately horizontal movement of the waters from higher towards lower latitudes.

The part of the ocean signalised by high specific gravities, from the surface down at every stage to the bottom, is beyond all comparison that region of the North Atlantic tabulated above. This becomes the more pronounced as the greater depths are reached, viz., depths under 400 fathoms, Maps 6 and 7, a result doubtless to be traced to the outflowing under-current of high specific gravity from the Mediterranean. But, unfortunately, we must wait for observations from the regions to the north of lat. 40° N. and from Brazil to the north-east towards the routes followed by the "Challenger," ere the far-reaching influence of this powerful under-current can be properly represented.

The region of high specific gravity next in order is that of the South Atlantic, which is less at the surface and at great depths, but nearly the same from 100 to 400 fathoms, Maps 2 to 5. At depths exceeding 800 fathoms it is markedly less than in the North Atlantic, being, however, at these depths all but equal to the specific gravities found in the deeper waters of the Pacific to the east of Australia, Map 7. A most regrettable blank in the South Atlantic observations of specific gravity and temperature at depths exceeding 800 fathoms is from the coast to, say, 30° of west longitude seaward

from Bahia to the La Plata. Observations made in this region would fill up the blank to westward and southward of the "Challenger" and "Gazelle" courses. From the one or two such observations made, it is evident that abnormally cold water fills the deep-sea basin there, and, from its necessarily greater specific gravity, must exercise a powerful influence on oceanic circulation.

Owing to the low temperature of the higher latitudes the specific gravity there is greatly in excess, but the excess diminishes with depth (Maps 2 to 7) as the temperature of the ocean approaches to uniformity. The most remarkable differences are shown at 100 fathoms in the specific gravity in the intertropical part of the West Pacific as compared with the specific gravities to the north and south. Thus, in the Yellow Sea to the west of Nagasaki, the specific gravity is 1·0257; whereas, in the Sea of Japan, in lat. 40°, it is 1·0272. A little to the north-east of Australia it is 1·0247, but to the east of Sydney it is as high as 1·0271.

At depths exceeding 1500 fathoms the geographical distribution of salinity and specific gravity, as shown by the departure above or below their respective averages, approximately coincide, owing to the great uniformity of temperature at these great depths. Map 7 shows the distribution of the specific gravity at depths exceeding 1500 fathoms, and Map 9 the salinity. Map 9 confirms the important result that it is just in those regions where the surface salinity is high that the bottom salinity and specific gravity is also high; and it is just in the regions where the surface salinity is low that the bottom salinity and specific gravity is also low, thus showing a close connection between the salinities of the surface and the bottom of the ocean.

Another very striking feature is that these areas of high salinity carry down with them to the bottom a comparatively high temperature, with which they are characterised at less depths and at the surface.* Owing to this higher temperature the differences in the geographical distribution of the specific gravities are less than those of the salinities, and hence the movement resulting from the different degrees of saltness at great depths is less than would otherwise be the case. The most conspicuous instance of these regions of high salinities and temperatures down to the bottom is afforded by the North Atlantic. If the extent of the area embraced by the high salinities be examined at the different depths, the extent would appear rather to increase with the descent.

In the Pacific Ocean, to the east of long. 140° E., no single observation yet made shows a salinity above the average, thus indicating an expansion of the area of low salinity in the North Pacific. The few observations off the west coast of South America, from the equator southwards, are all under the average. Similarly, the area of low salinity in the Gulf of Guinea is more pronounced and of wider extent at great depths than it is at less depths and at the surface.

It would appear from the outstanding features of the regions of exceptionally high and exceptionally low salinities that the ocean through its depths is more completely influenced by its downward movements than it is through its wide extent by its horizontal

* See Challenger Report, Temperature Maps.

movements. It may be remarked that, while the general depth is measured by two or three miles, the extent is measured by thousands of miles.

Attention may be drawn to a singular circumstance. While in the South Pacific, to the east of long. 140° W., none of the observed salinities are above the average to the south of lat. 33° S., in the South Atlantic the separating line is about lat. 40° S., and in the Indian Ocean, lat. 43° S. The differences are probably due to the regions in the different oceans of the great ice-meltings that take place.

Leaving out of view the movements of the waters of the ocean caused by winds, all other movements, whether vertical or horizontal, must be referred to differences of specific gravity. But while this is so, it is seen that for movements of great bodies of waters which have actually been effected, the maps of salinity furnish equal if not more authoritative information as to how the transference has been effected from one region to another, or from one depth to another. This arises from the extensive serious blanks which occur in all parts of the ocean, rendering it impossible in many cases to trace these movements in their progress from one region to another.

In the South Atlantic it is seen that at all depths the temperature and salinity are very greatly lower off the coast of Africa, whence the prevailing winds blow, than off the coast of South America, towards which they blow. Further, that the layers of warm water at or near the surface, which are everywhere little more than a mere film as compared with the mass of cold water beneath, are very greatly thinner on coasts where the wind blows seaward from the land, than off the coasts on which the prevailing wind blows home. This peculiarity holds good in all parts of the globe. In the one case cold water upwells to supply the drain on the surface waters by the winds driving them from the coasts, and in the other the prevailing winds drive the warm surface waters before them, and thus cause an accumulation of warm water of very considerable thickness along the coasts they strike. In this connection Dr MURRAY has pointed out that there are no coral reefs off the western shores of Africa or of America, because they have not there the high temperature they require. They are found, however, off the lee shores of tropical and sub-tropical regions, whither prevailing winds transport the waters of high temperature on which the existence and well-being of the corals depend.

There is a different type of upwelling in the Pacific, Atlantic, and Indian Oceans, which is best examined through the temperatures.* The most important of these is in the Pacific, and may be briefly described. Within the area of this remarkable upwelling the "Challenger" took serial temperatures in lat. 7° 35′ N. and long. 149° 49′ W. In contrast with these, other serial temperatures were observed across the equator in lat. 11° 20′ S. and long. 150° 30′ W., this point being on the eastern side of the high temperature and high salinity area to the east of Australia. The following extracts from the "Challenger" soundings, Nos. 410 and 417, taken respectively on August 10th and September 14th, 1875, will show the extraordinary differences in the rates of change of temperature

* For a more detailed account of these see the Challenger Report, p. 19. Consult also Maps 3 and 4 of that Report.

with depth at these two points down to 200 fathoms, the distance between the two stations being about 1140 miles :—

SERIAL TEMPERATURES.

Depth in fathoms.	Lat. 7° 35′ N. Long. 149° 49′ W.	Lat. 11° 20′ S. Long. 150° 30′ W.	Difference of Temperature.
Surface.	81°·0	80°·0	+ 1°·0
20	79·3	79·8	− 0·5
30	79·3	79·6	− 0·3
45	78·2	79·4	− 1·2
50	74·0	79·0	− 5·0
60	63·4	78·0	− 14·6
70	56·2	76·7	− 20·5
80	52·6	75·3	− 22·7
90	51·0	73·7	− 22·7
100	50·3	72·0	− 21·7
120	49·8	68·3	− 18·5
140	49·4	64·0	− 14·6
160	49·0	58·9	− 9·9
180	48·6	54·2	− 5·6
200	48·2	50·8	− 2·6

In the one case, there is upwelling by which the cold water of lower depths is raised towards the surface, so that at 90 fathoms its temperature is 22°·7 lower than it is at the same depth in the position south of the equator only 1140 miles distant. The observations point to this region of extensive upwelling as one of the chief sources of supply of the water of the surface currents of the Pacific which accompany the trade winds of this ocean. Since the temperature for a great distance all round this cold area is higher, it follows that the origin of this low temperature can only be derived from greater depths.

But the salinity of these two regions is as equally marked as the temperature. The station south of the equator here given is the nearest to the station above at which serial salinities were observed.

SERIAL SALINITIES.

Depth in fathoms.	Lat. 7° 35′ N. Long. 149° 49′ W.	Lat. 13° 28′ S. Long. 149° 30′ W.
Surface.	1·0257	1·0263
25	256	267
50	258	268
100	257	269
200	256	257
300	255	256
400	255	255

Thus, the station south of the equator indicates a very high salinity, which steadily increases from the surface down to at least 100 fathoms, the station being within the region of great salinity lying in the Pacific to the east of Australia. On the other hand, the station north of the equator shows a salinity varying but little from the surface down to 400 fathoms. The only possible explanation is that at this station there is upwelling from lower depths, bringing up to the surface water of comparatively low temperature and low salinity so characterisic of the deeper waters of the ocean; and in this connection it falls to be noted that it is immediately to the east of this cold region where the east flowing current of this part of the equatorial region of the Pacific has its origin.

Analogous to this is the most striking illustration afforded by the ocean anywhere in what takes place, in all probability, in intertropical seas from the bottom upwards. This is in the lifting up, or upwelling, of the cold water beneath, by which is made good the loss which takes place from the excess of the water lost from evaporation as compared with what is received from the rainfall, and the loss occasioned from the powerful poleward ocean currents of higher latitudes, which are originated and maintained by the strong south-westerly winds of the Northern Hemisphere and the still stronger west-north-westerly winds of the Southern Hemisphere.

Conclusions.

The prevailing winds, in their direct and indirect effects, are the most powerful agents concerned in oceanic circulation. They originate and maintain the surface currents of the ocean, and the influence of these currents is, through friction, felt to a depth of probably several hundred fathoms. In intertropical regions the prevailing trade winds drive the surface currents westwards to the eastern shores of the continents, and there, accordingly, a greater depth of warm water is found occupying the upper layers of the ocean than elsewhere; and, except where the rainfall is abnormally heavy, this water is not only very warm, but it has acquired from evaporation a salinity much higher than the general average of the ocean. The results over the face of the ocean have been already described, and may be studied in greater detail on Map 1 of the Challenger Report. It is one of the most remarkable results of this inquiry that these areas of high surface temperature and high salinity are found represented at all depths down to the bottom, with just a tendency to an extension of the areas with increase of depth. It follows that, waiving in the meantime what takes place at the bottom, the great mass of the ocean intermediate between the upper layers and the bottom principally exhibits vertical movements.

On the other hand, on the eastern sides of the oceans whence the trade winds start on their course, there is an upwelling of the colder water of the greater depths towards the surface in a manner similar to what Dr Murray has shown happens in the case of our Scottish lochs when strong winds sweep over their surfaces.* In such cases the warmer

* *Proceedings*, vol. xviii. pp. 142–43.

surface water is blown to the leeward shores of the lochs, and colder water, by upwelling, rises to the surface on the wind-shore of the lochs. These cold areas of a lower surface temperature and salinity are also continued down to the bottom, with a tendency to an expansion of the areas with descent.

The ice-cold water which occupies the bottom of the ocean in all latitudes necessitates a constant supply of water of a very low temperature from the deep water of the Southern and the Antarctic Oceans, and in a less degree the Arctic Ocean. This slow moving current of cold water along the bottom of all parts of the ocean is effected, on the one hand, by the reduction, in the intertropical regions, of the surface waters by evaporation and by the extratropical prevailing winds blowing polewards, and on the other by the greater specific gravities of the ocean in high latitudes and the "head" of water accumulated there by the prevailing south-westerly winds of the northern and the prevailing north-westerly winds of the southern hemisphere.

The increase of the temperature which may be considered as setting in from 1500 fathoms upwards to the surface, implies that this excess of temperature has its origin wholly in the surface temperature. The restricted extent and continuity through all depths of these two contrasted areas may be regarded as the balance struck by the forces which produce the upward movement, in lifting the cold water of great depths towards the surface, and the downward movement in transferring the surface warmth to greater depths. The result would have been materially different if the depth of the ocean with respect to its extent had not been so insignificant as it is. But additional experiments on a large scale and observations are needed before these upward and downward movements in the ocean which are conducted on so vast a scale can be explained, or even adequately described, as to the way in which they are effected.

There are subsidiary causes powerfully influencing oceanic circulation, the chief of which are abnormally heavy rainfall, such as occurs in the west of the Pacific; undercurrents of a high temperature and specific gravity from the Mediterranean and Red Seas; the causes leading to the extensive upwelling seen in the Pacific to the south-east of the Sandwich Isles, and analogous positions in the Atlantic and Indian Oceans, which are closely connected with the supply of a portion of the water of the great surface currents of these oceans; and the intertropical position of the line of lowest mean barometric pressure, resulting in a temperature much higher in the North than in the South Atlantic, and much higher in the South than in the North Pacific Ocean.

[APPENDIX.

APPENDIX.

The following are the sources of information from which the specific gravities at depth of 100 fathoms and greater depths have been obtained :—

1. Report on the Specific Gravity of Ocean Water, observed on board H.M.S. "Challenger" during the years 1873–76. By J. Y. Buchanan, M.A., F.R.S.E. (*Phys. Chem. Chall. Exp.*, pt. ii., 1883).

2. The Exploration of the Gulf of Guinea. By J. Y. Buchanan, F.R.S. (*The Scottish Geographical Magazine*, vol. iv., 1888).

3. The Norwegian North Atlantic Expedition, 1876–78 (The North Ocean: its Depths, Temperature, Specific Gravities, and Circulation). By Professor H. Mohn, Christiania, 1887.

4. Report on Scientific Researches carried on during August, September, and October 1871 in H.M. Surveying Ship "Shearwater." By William Carpenter, M.D., LL.D., F.R.S. (*Proc. Roy. Soc.*, vol. xx. p. 535, 1871).

5. Die Forschungsreise, S.M.S. "Gazelle" in den Jahren 1874 bis 1876, unter Kommando des Kapïtän zur See Freiherrn von Schleinitz; herausgegeben von dem Hydrographischen Amt des Reichs-Marine-Amts, Berlin, 1889.

6. Journal of Hydrological Observations made by Officers of the Corvette "Vitiaz" during a Voyage of Circumnavigation, 1886–89. By Admiral Makaroff, Admiralty, St Petersburg, 1894.

7. Berichte der Commission für Erforschung des östlichen Mittelmeeres, Erste und Zweite Reihe (Denkschr. d. k. Akad. Wiss. Wien Bd. lix. and lx.).

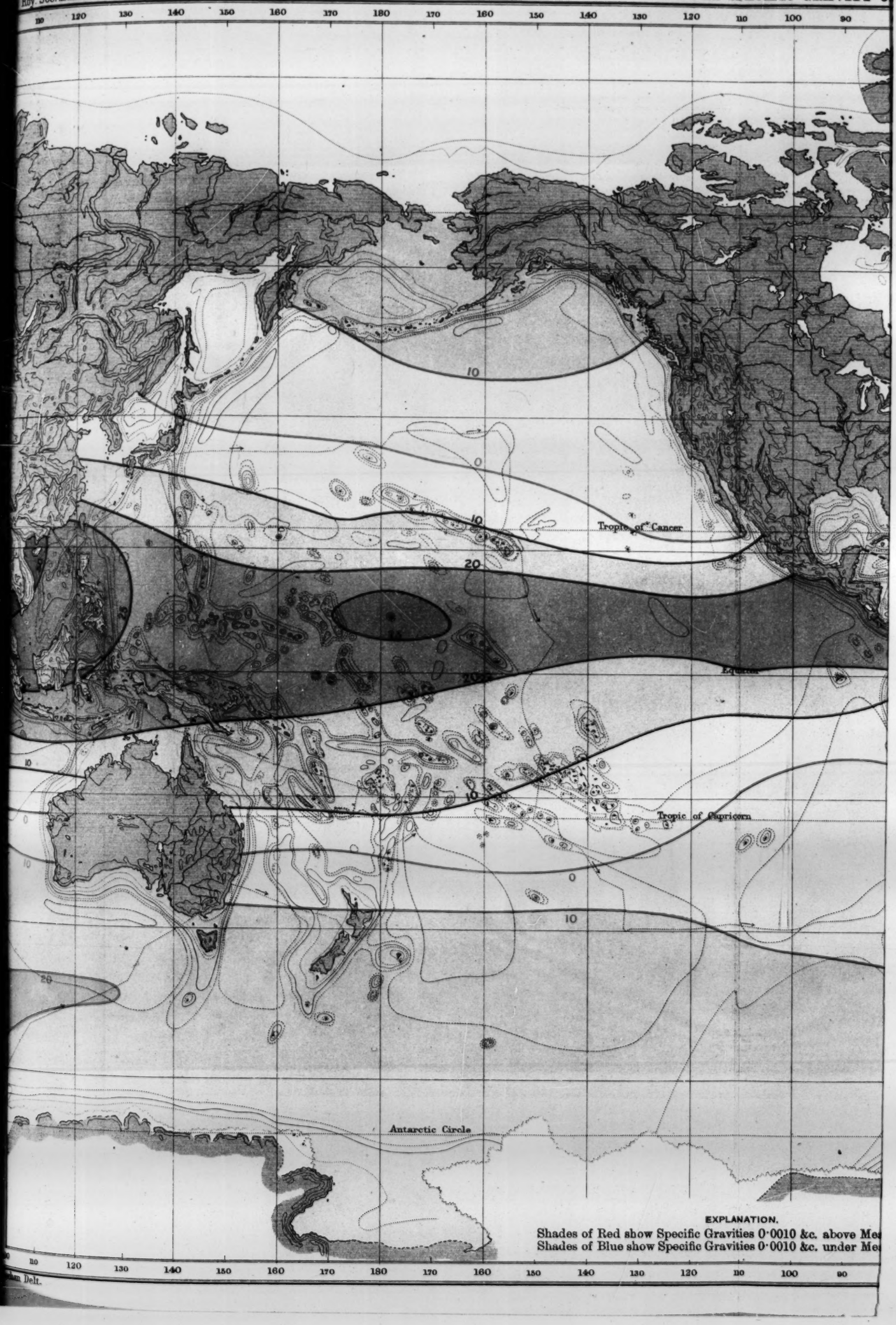
8. Observations from Soundings taken by the Indiarubber and Telegraph Works Company (various years).

9. Report on Physical Observations on the Sea to the West of Lewis in 1887. By Hugh Robert Mill, D.Sc., F.R.S.E. (Fishery Report, 1888).

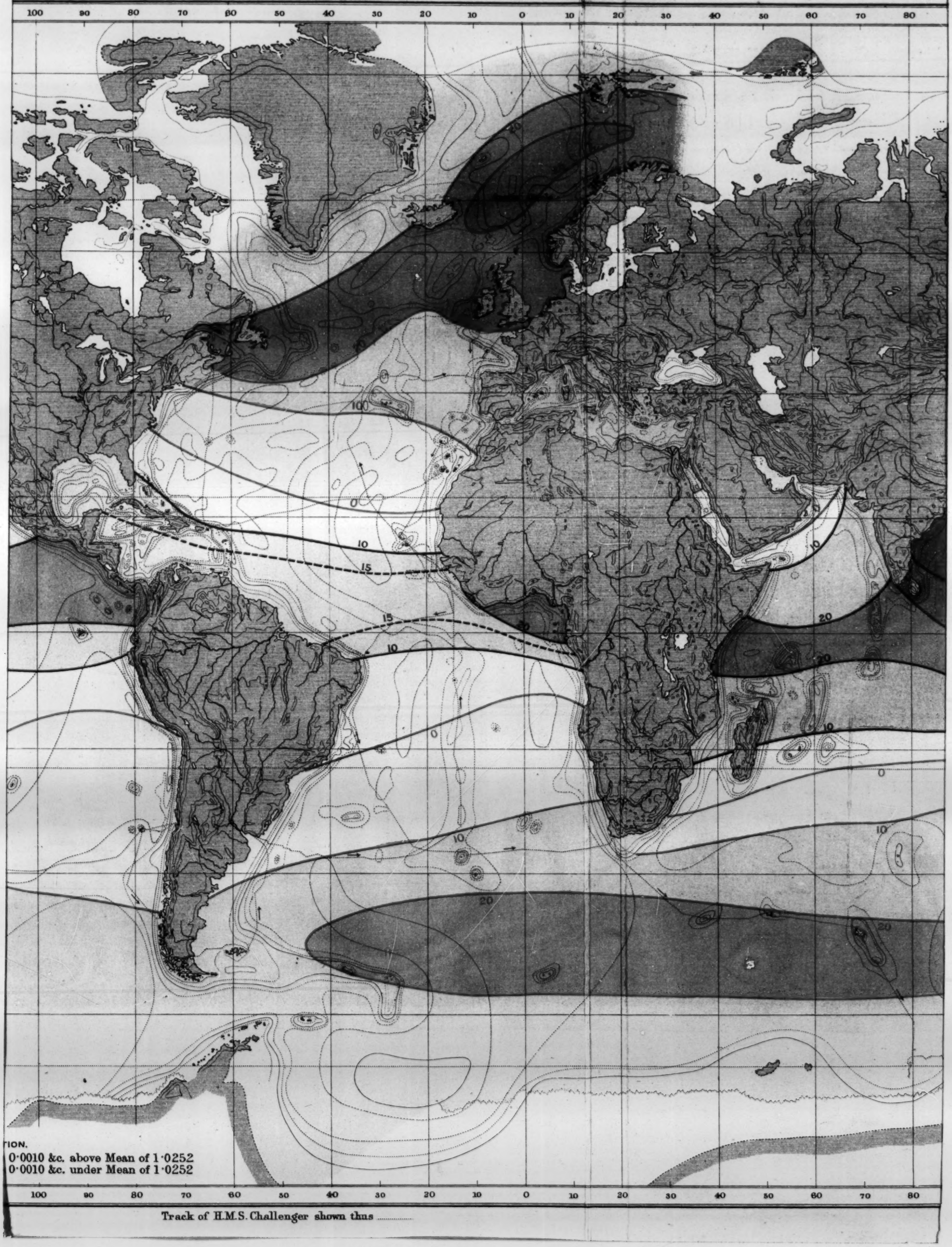
10. Report on Physical Observations carried out on board H.M.S. "Jackal," 1893–94. By H. N. Dickson, F.R.S.E., F.R.G.S. (Report of the Fishery Board for Scotland for 1893).

11. Resultaten af den Svenska Hydrografiska Expeditionen År 1877 under Ledning af F.L. Ekman. Efter F.L. Eckmans Död utarbetad af Otto Pettersson, Stockholm.

ANNUAL SPECIFIC GRAVITY O



FIC GRAVITY OF SURFACE OF THE OCEAN AT TEMPERATURE OF OBSERVATION = 1·0252.



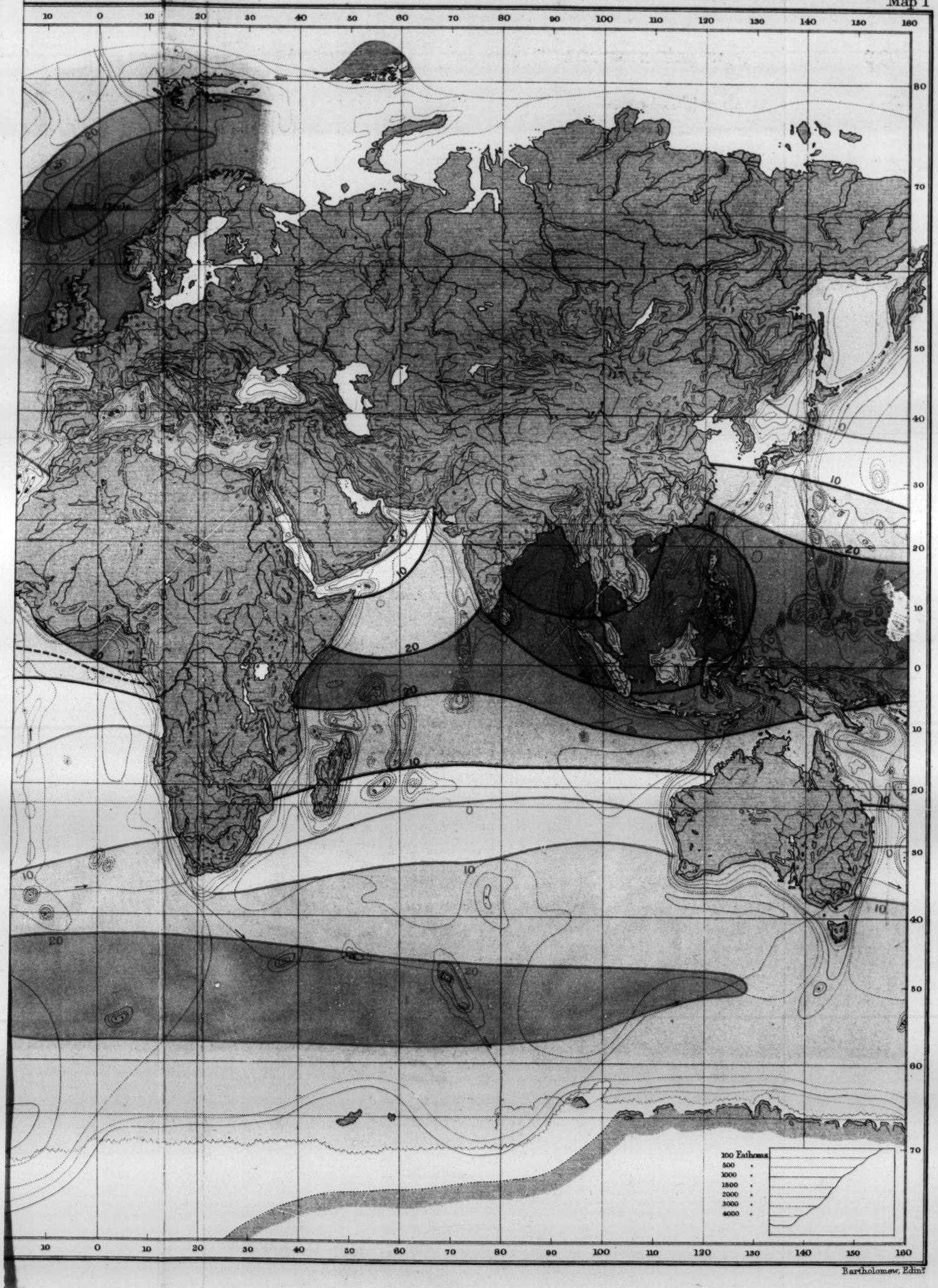
TION.

0·0010 &c. above Mean of 1·0252
0·0010 &c. under Mean of 1·0252

Track of H.M.S. Challenger shown thus .....

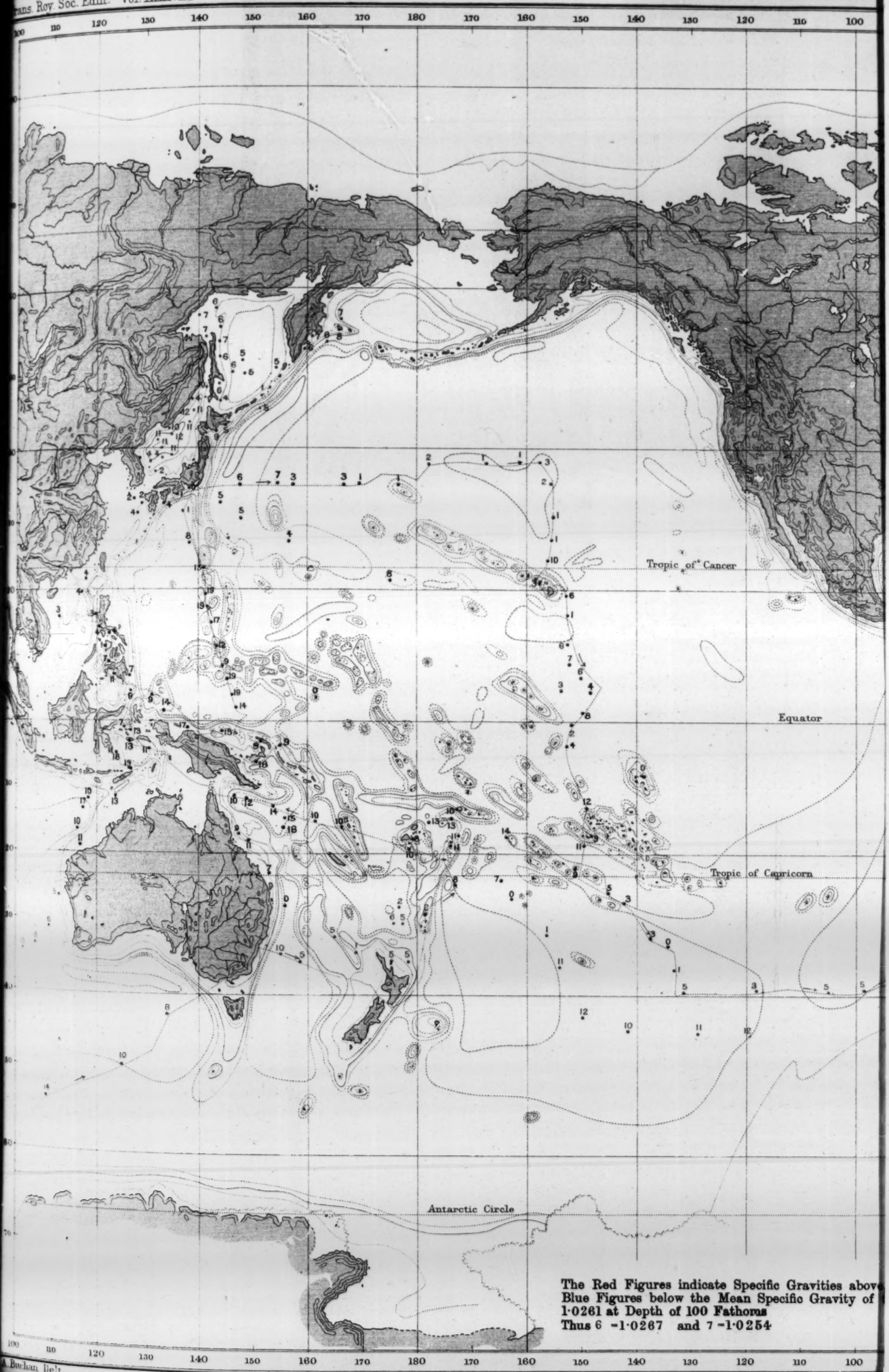
RE OF OBSERVATION = 1·0252.

Map 1



Bartholomew, Edin.

MEAN SPECIFIC GRAVITY OF



CIFIC GRAVITY OF THE OCEANS. AT OBSERVED TEMPERATURE OF SEA. AT DEPTH OF 100 FATHOMS = 1·0261

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60

Arctic Circle

Equator

ic of Capricorn

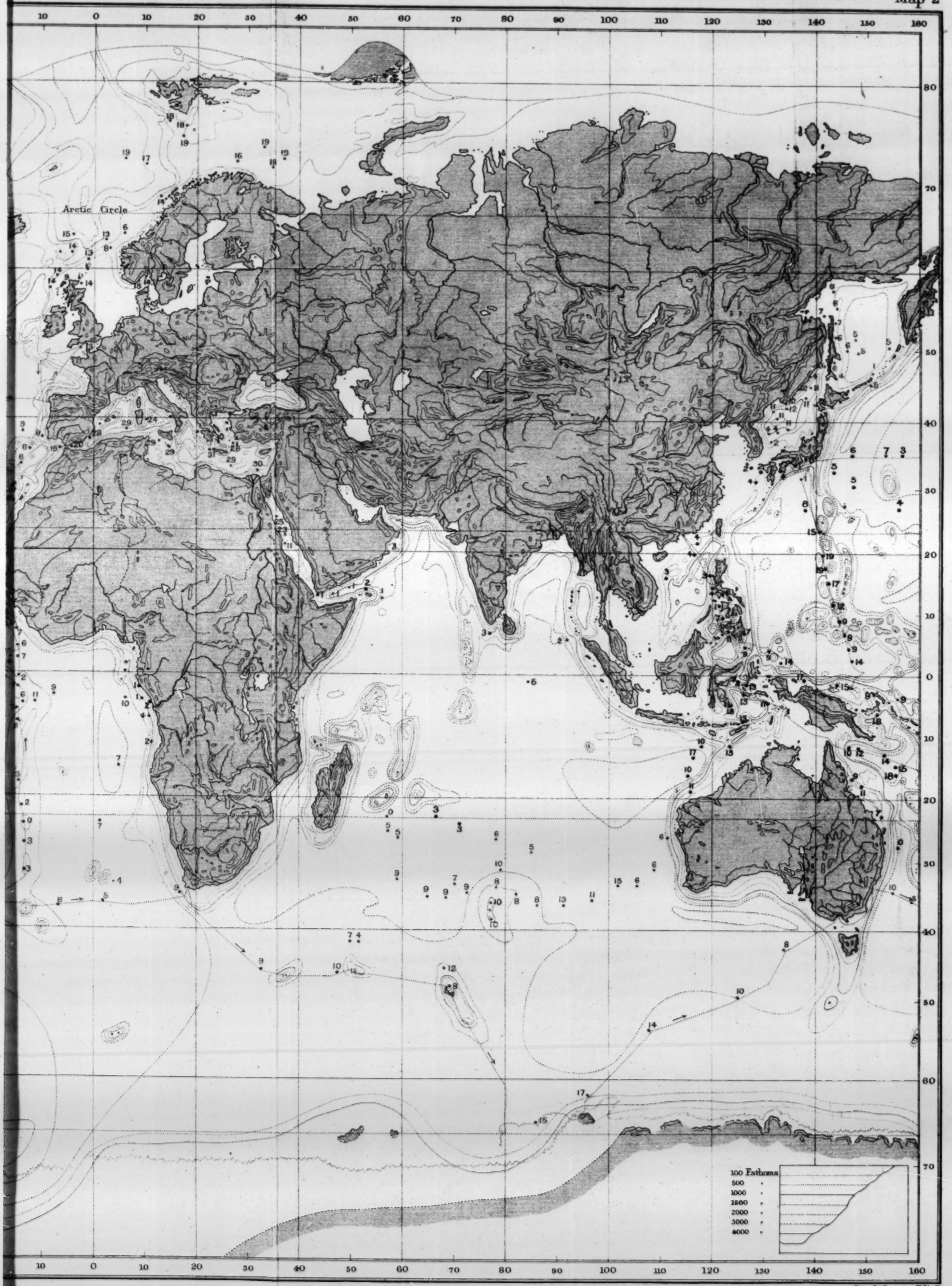
Specific Gravities above, and the
ean Specific Gravity of the Ocean
thoms
·0254

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 7

Track of H.M.S. Challenger shown thus .....

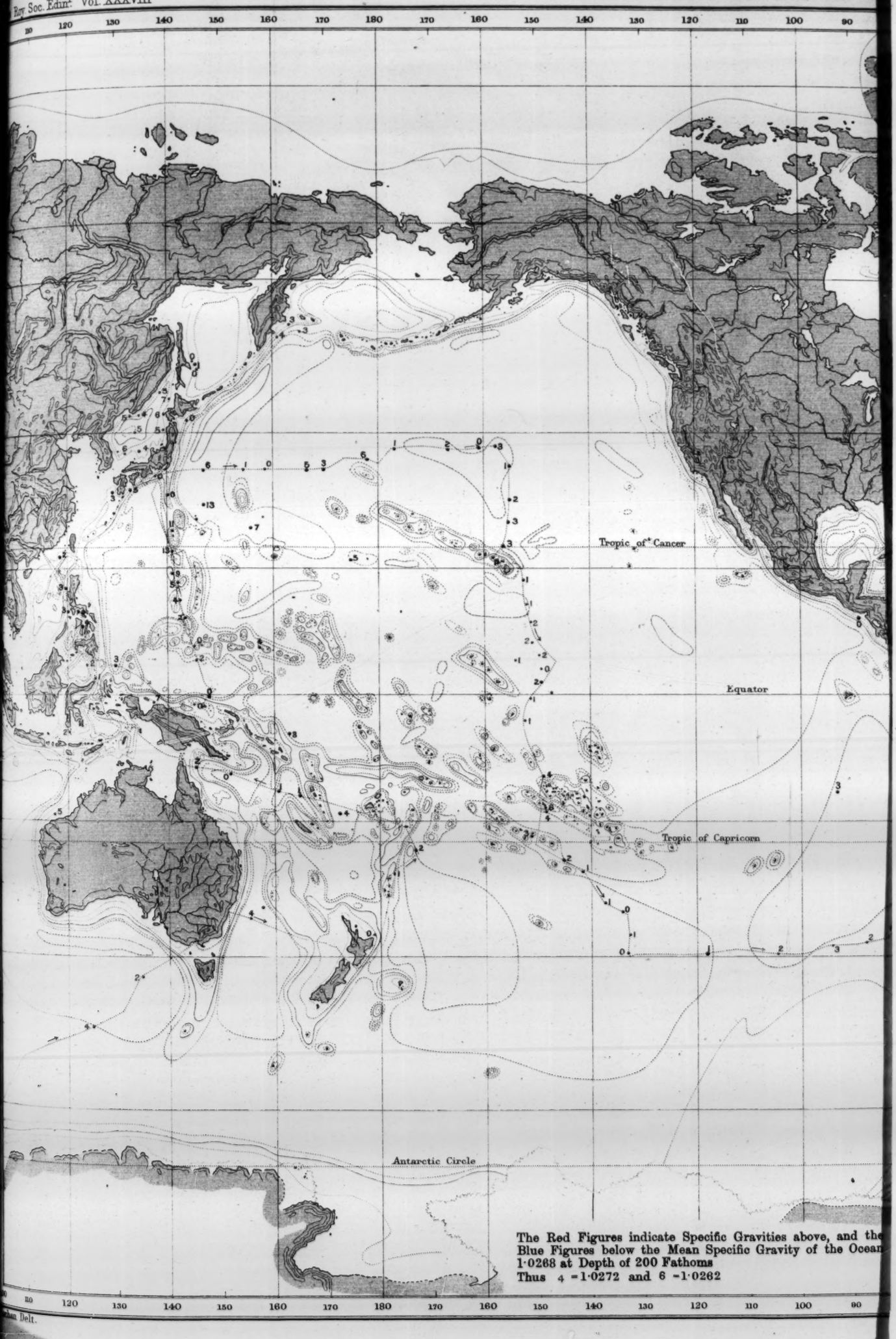
. AT DEPTH OF 100 FATHOMS = 1·0261

Map 2



Bartholomew, Edin.

MEAN SPECIFIC GRAVITY OF THE O



The Red Figures indicate Specific Gravities above, and the Blue Figures below the Mean Specific Gravity of the Ocean 1·0268 at Depth of 200 Fathoms
Thus 4 = 1·0272 and 6 = 1·0262

GRAVITY OF THE OCEANS, AT OBSERVED TEMPERATURE OF SEA, AT DEPTH OF 200 FATHOMS=1·0268

110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

Arctic Circle

Equator

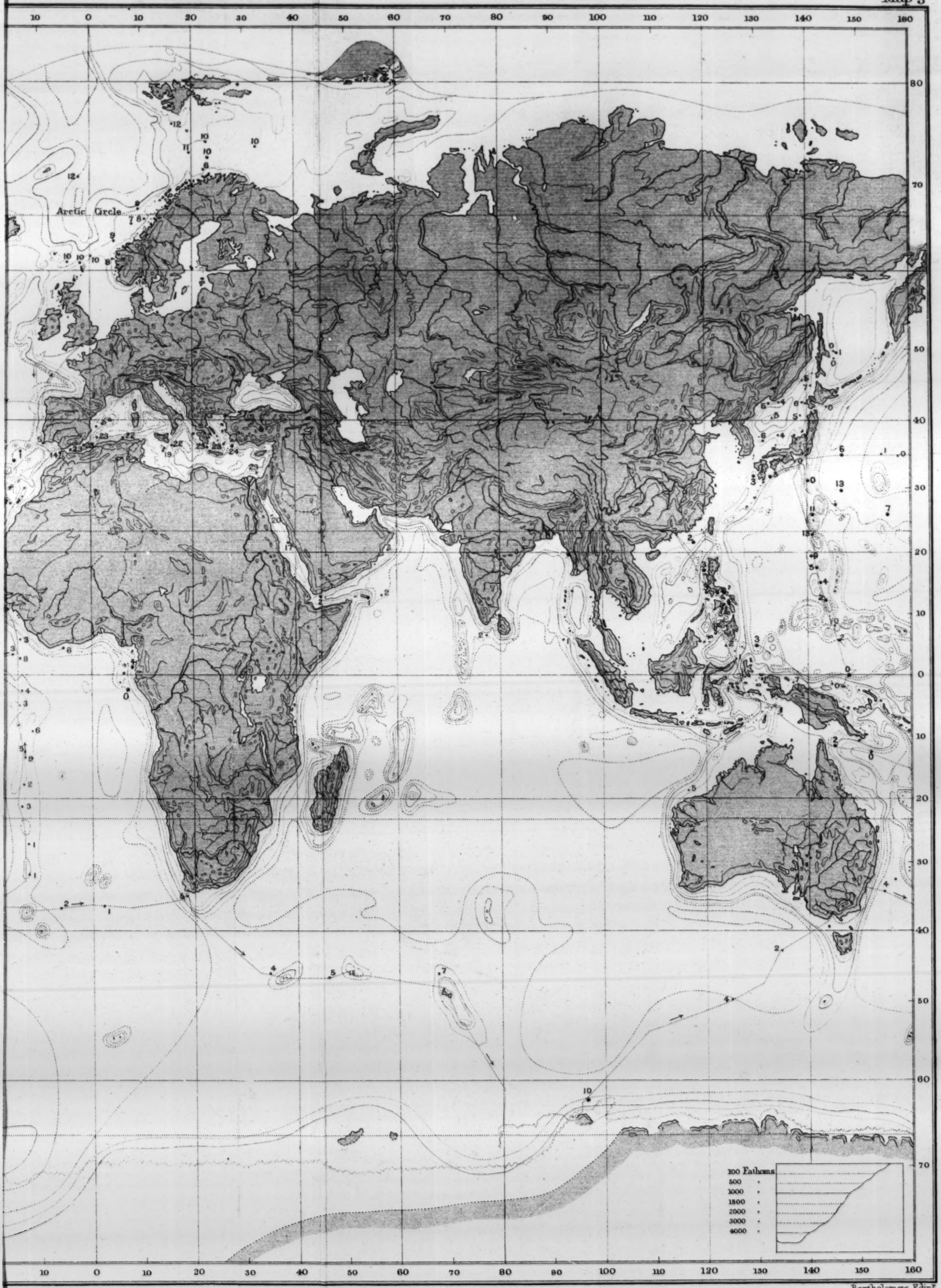
pricorn

c Gravities above, and the
ecific Gravity of the Ocean

Track of H.M.S. Challenger shown thus .....

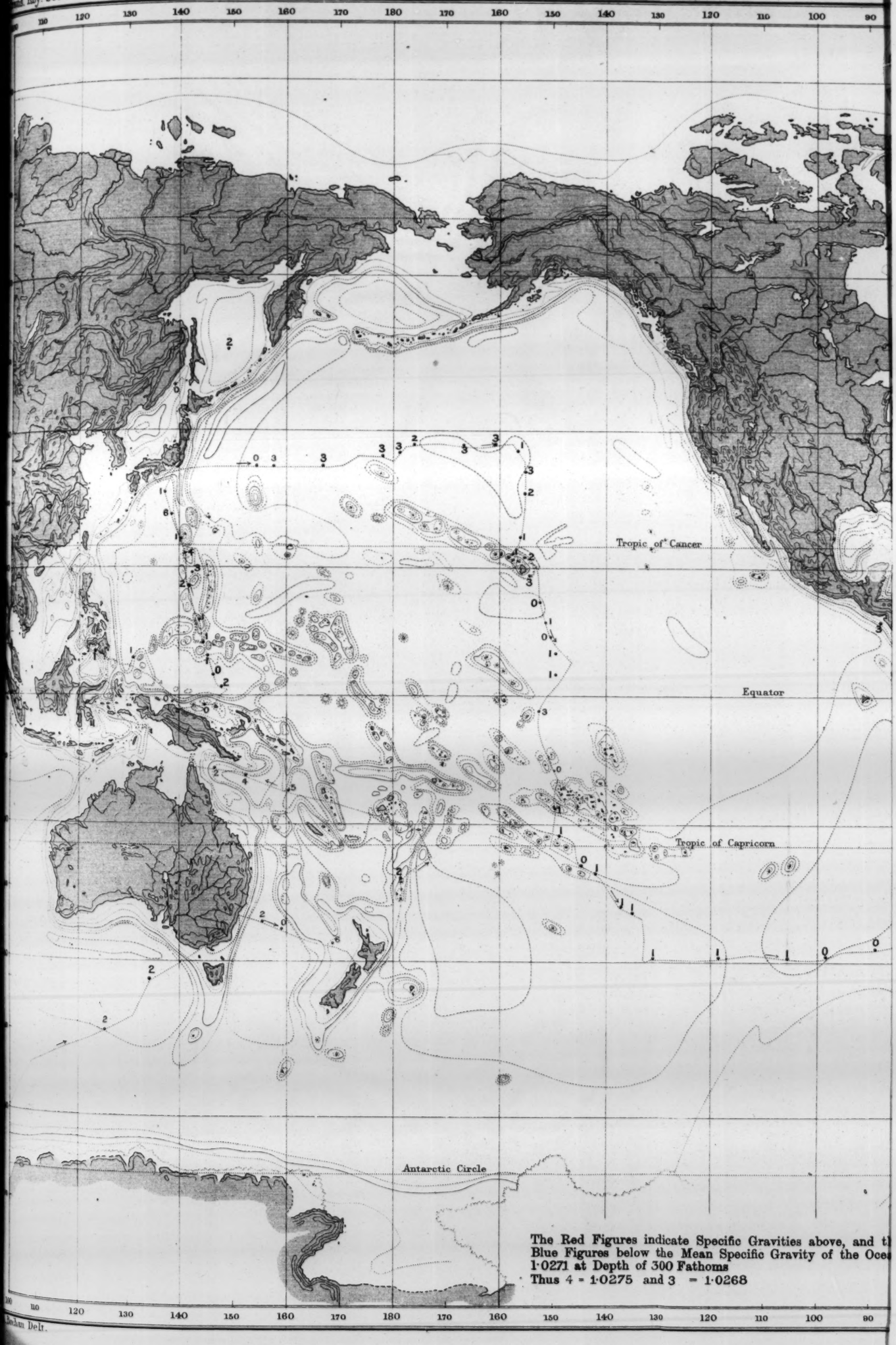
AT DEPTH OF 200 FATHOMS = 1·0268

Map 3



Bartholomew, Edin.

MEAN SPECIFIC GRAVITY OF THE



GRAVITY OF THE OCEANS, AT OBSERVED TEMPERATURE OF SEA, AT DEPTH OF 300 FATHOMS = 1·0271

110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

Arctic Circle

Equator

ricorn

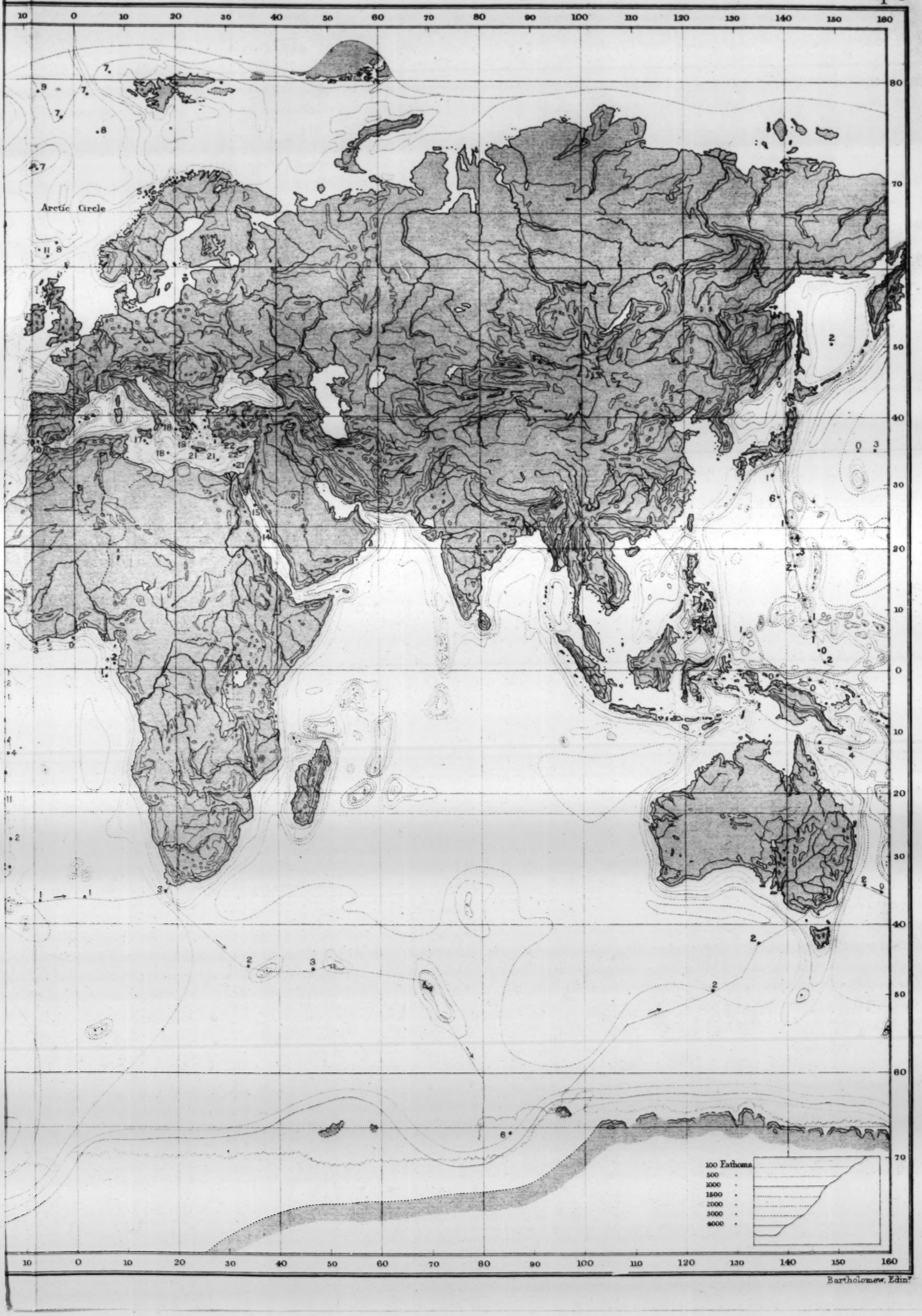
Gravities above, and the
ific Gravity of the Ocean

110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 8

Track of H.M.S. Challenger shown thus .....

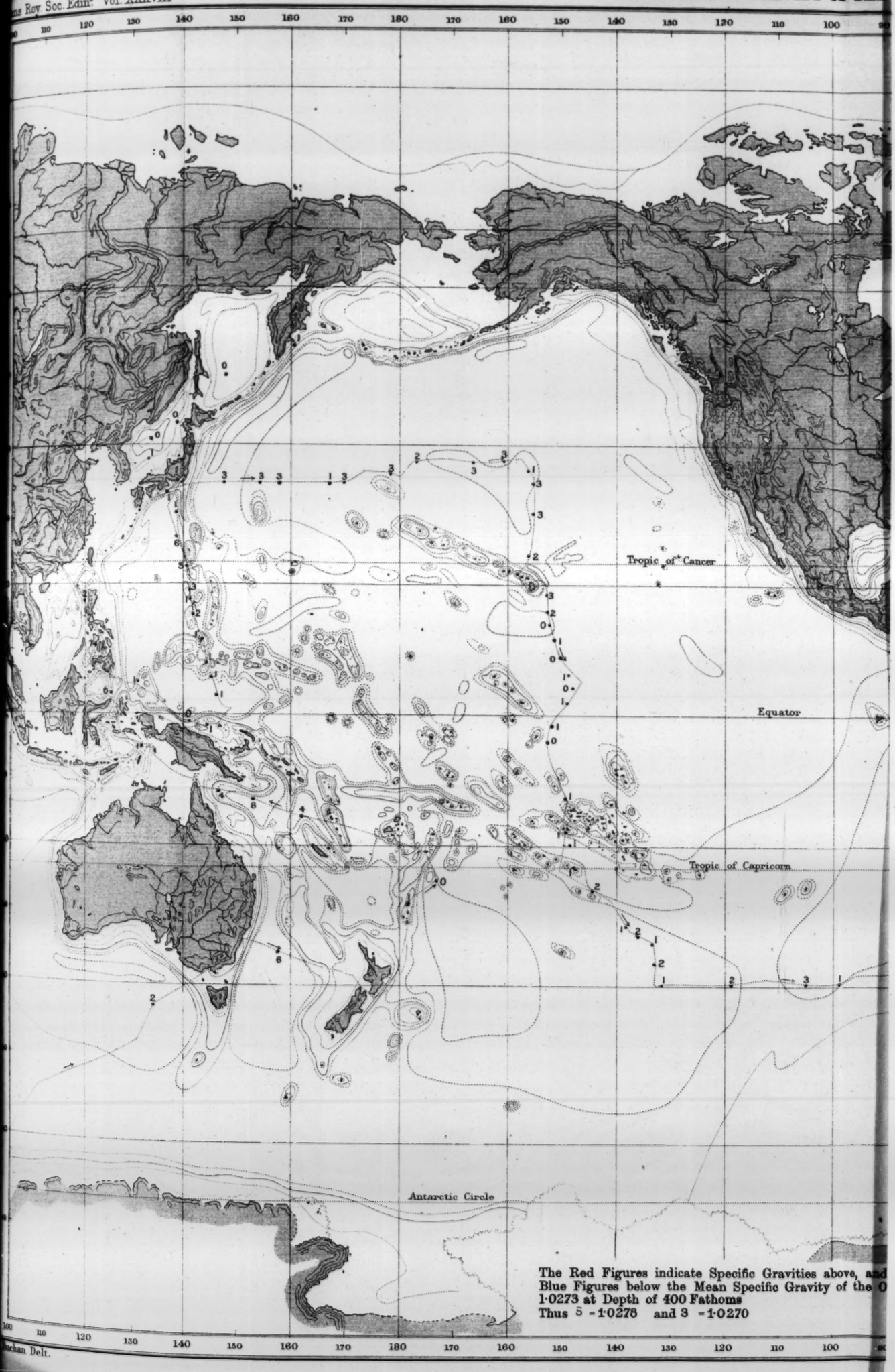
AT DEPTH OF 300 FATHOMS = 1·0271

Map 4



Bartholomew, Edin.

MEAN SPECIFIC GRAVITY OF THE



GRAVITY OF THE OCEANS, AT OBSERVED TEMPERATURE OF SEA, AT DEPTH OF 400 FATHOMS = 1·0273

110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

Arctic Circle

Equator

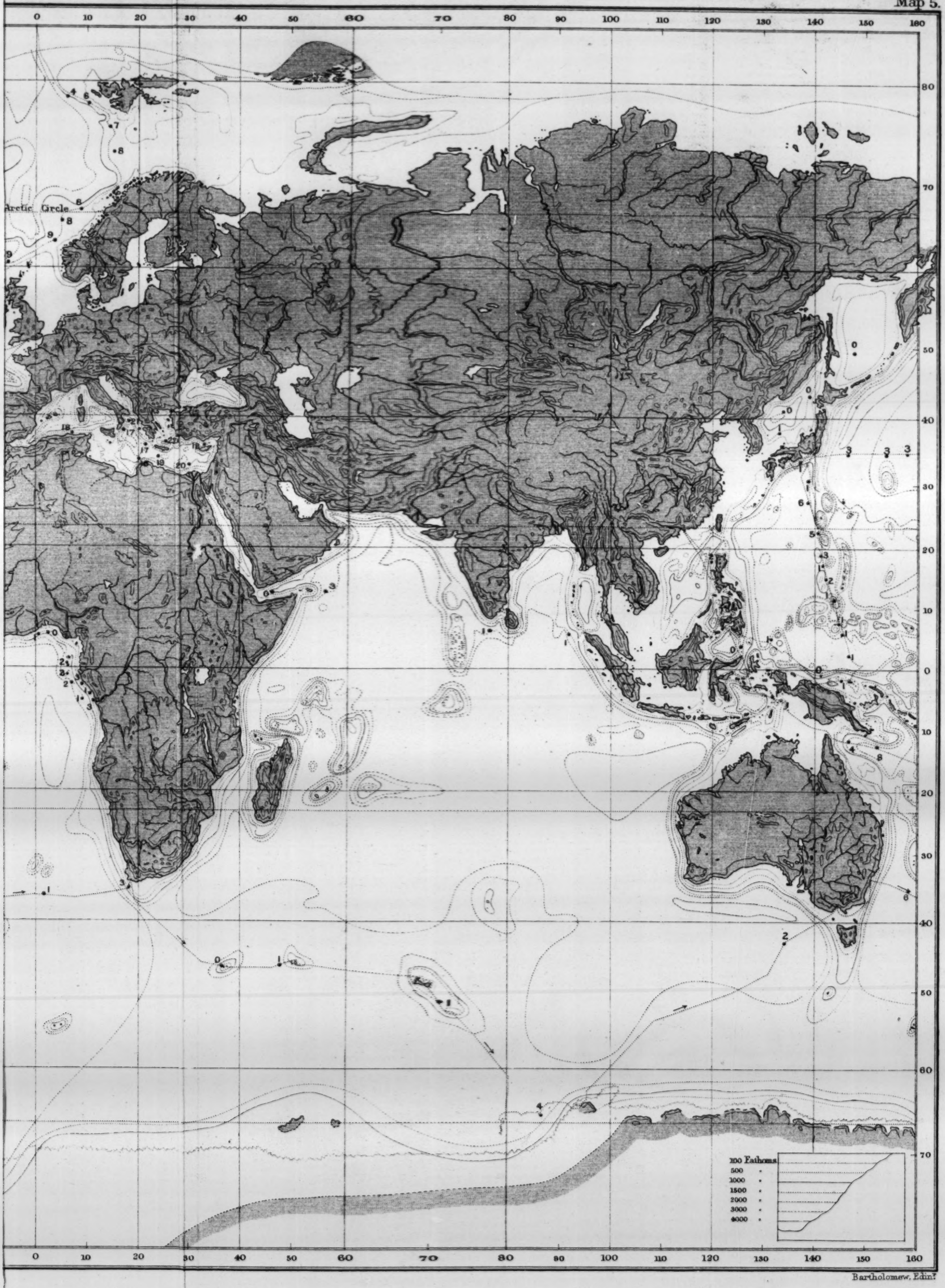
of Capricorn

pecific Gravities above, and the
n Specific Gravity of the Ocean
oms
0270

Track of H.M.S. Challenger shown thus .....

PTH OF 400 FATHOMS=1·0273

Map 5.



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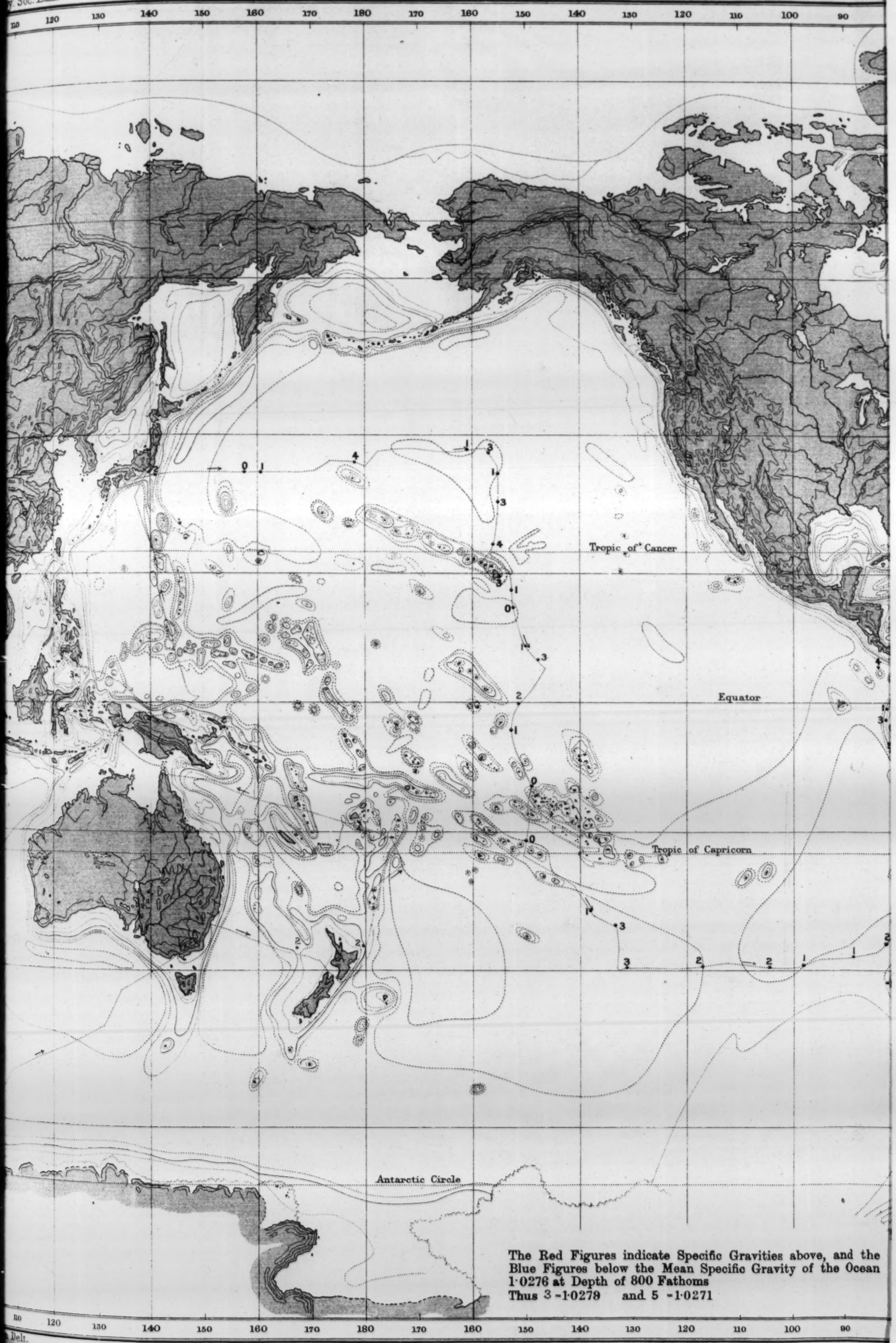
MEAN SPECIFIC GRAVITY OF THE OCE



The Red Figures indicate Specific Gravities above, and the Blue Figures below the Mean Specific Gravity of the Ocean 1·0276 at Depth of 800 Fathoms
Thus 3 -1·0279 and 5 -1·0271

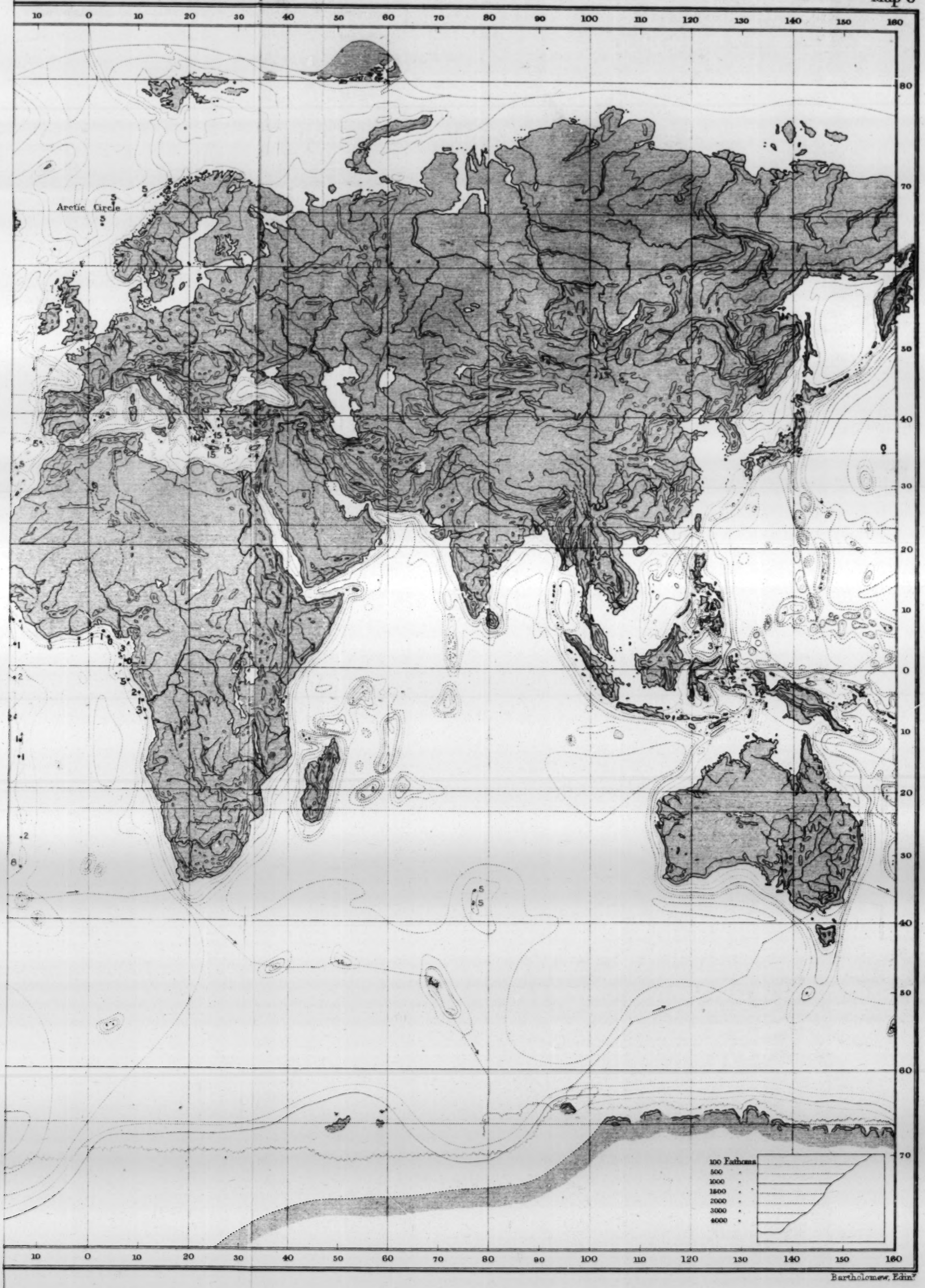
FIC GRAVITY OF THE OCEANS, AT OBSERVED TEMPERATURE OF SEA, AT DEPTH OF 800 FATHOMS=1·0276

Specific Gravities above, and the
ean Specific Gravity of the Ocean
thoms
1·0271

Track of H.M.S. Challenger shown thus .....

AT DEPTH OF 800 FATHOMS=1·0276

Map 6



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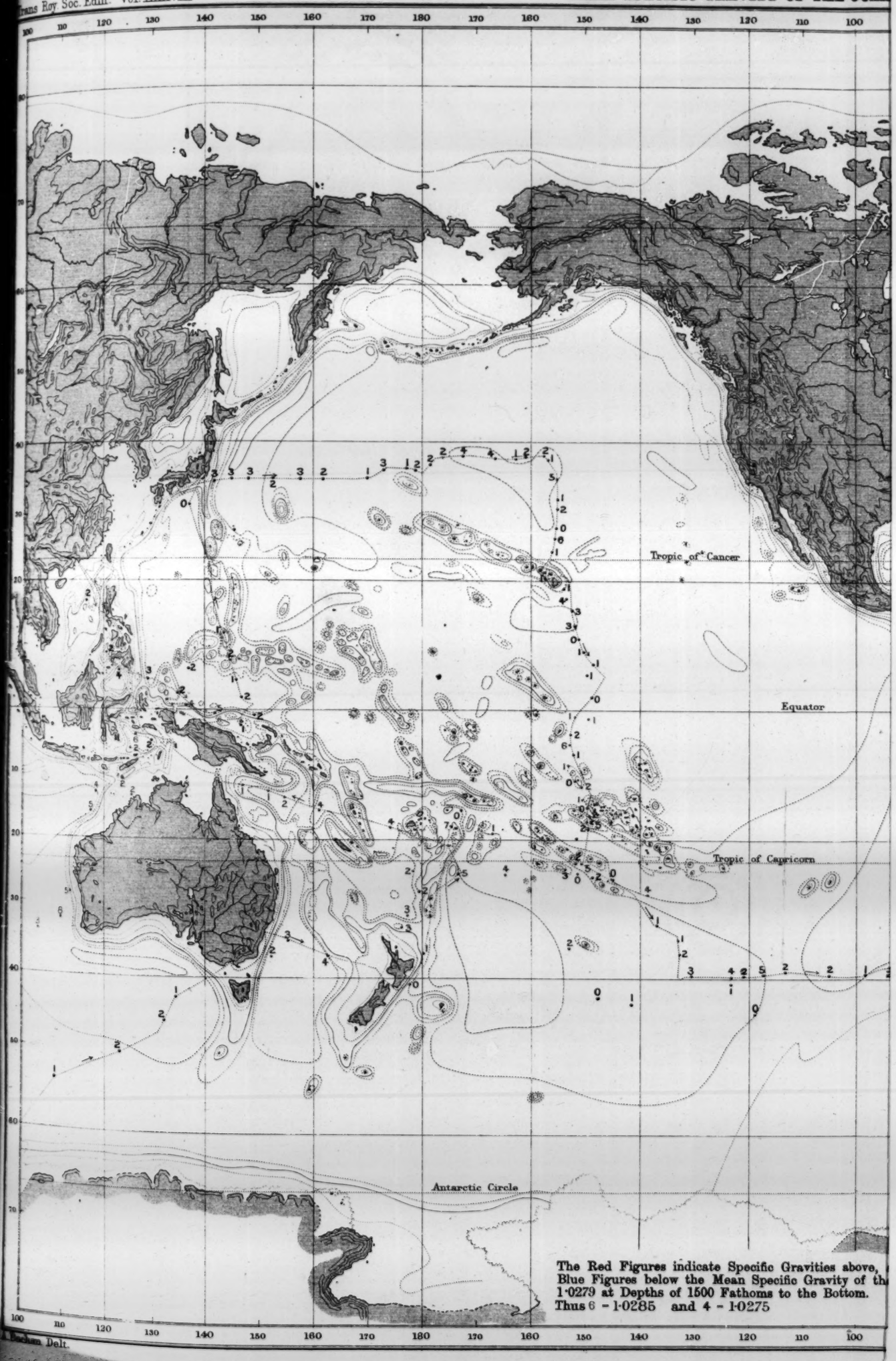
MEAN SPECIFIC GRAVITY OF THE OCEA



The Red Figures indicate Specific Gravities above,
Blue Figures below the Mean Specific Gravity of th
1·0279 at Depths of 1500 Fathoms to the Bottom.
Thus 6 - 1·0285 and 4 - 1·0275

TTY OF THE OCEANS, AT OBSERVED TEMPERATURE OF SEA, AT DEPTH OF 1500 FATHOMS TO THE BOTTOM=1·0279

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

Arctic Circle

Equator

ic of Capricorn

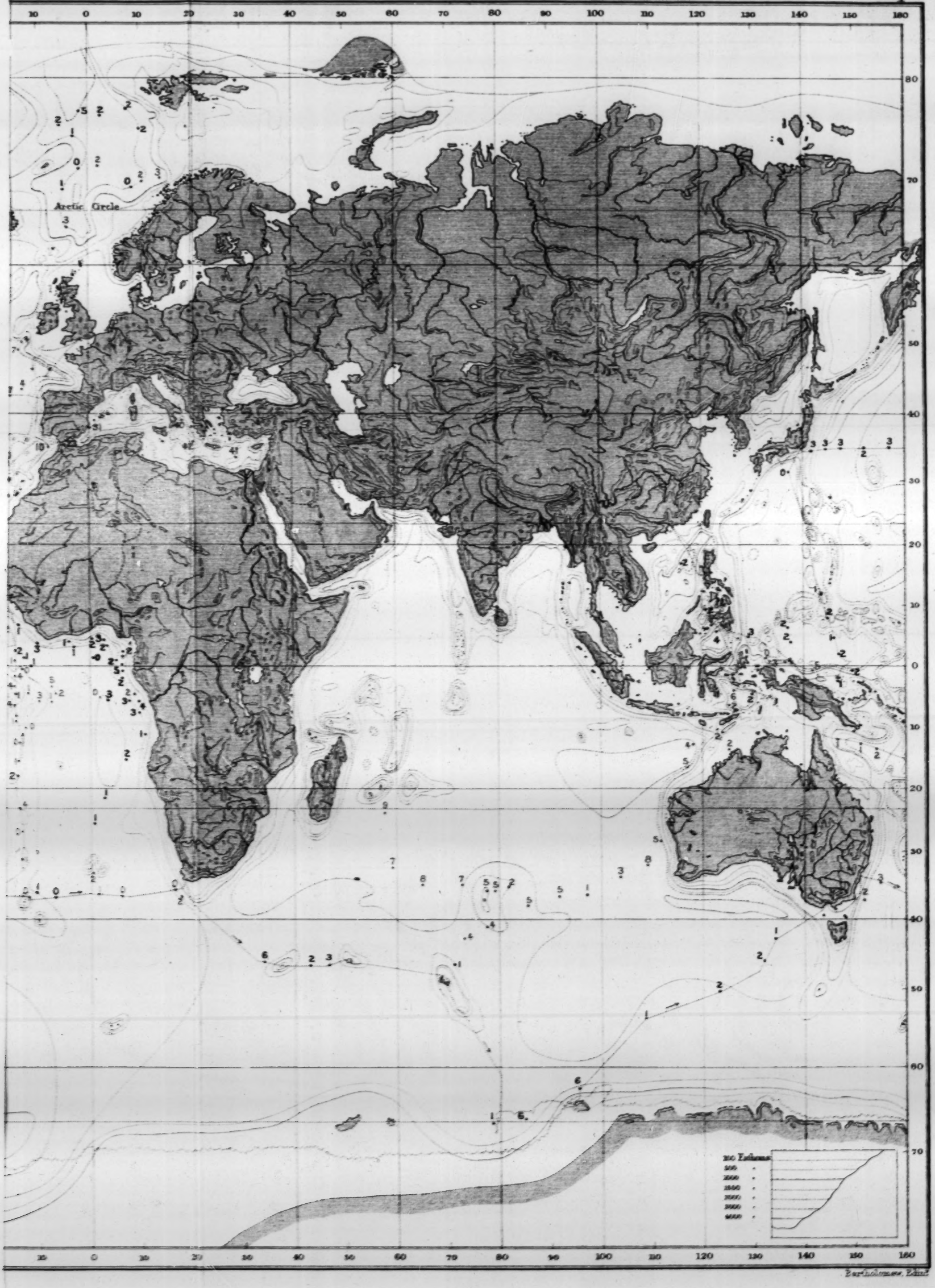
Specific Gravities above, and the
an Specific Gravity of the Ocean
athoms to the Bottom.
1·0275

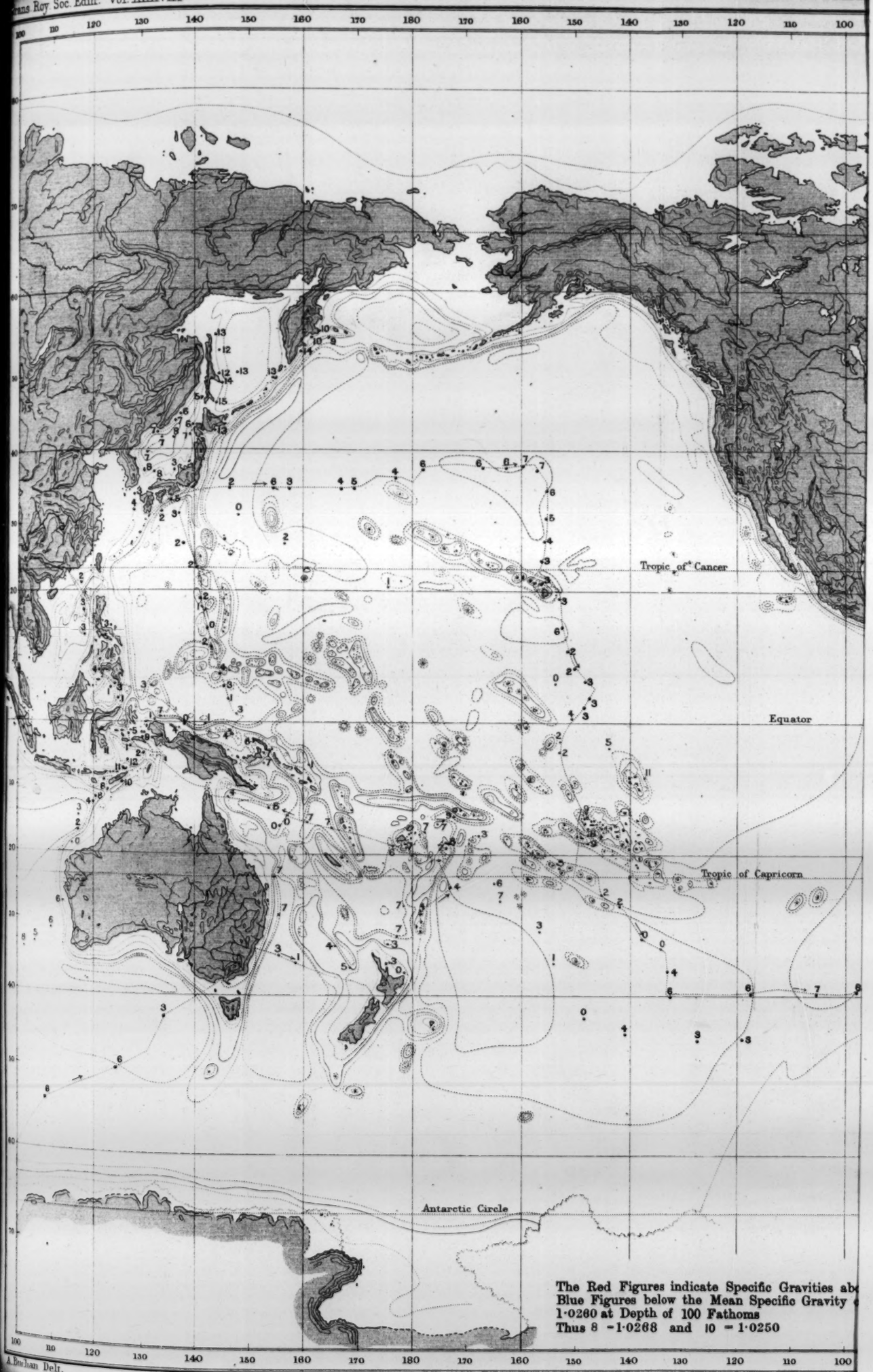
120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

Track of H.M.S. Challenger shown thus .....

H OF 1500 FATHOMS TO THE BOTTOM=1·0279

Map 7




Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
The Red Figures indicate Specific Gravities ab
Blue Figures below the Mean Specific Gravity
1·0260 at Depth of 100 Fathoms
Thus 8 = 1·0268 and 10 = 1·0250

MEAN SPECIFIC GRAVITY OF THE OCEANS, $S\left(\frac{60°}{39°2}\right)$ AT DEPTH OF 100 FATHOMS = 1·0260

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60

Arctic Circle

Equator

Tropic of Capricorn

ate Specific Gravities above, and the
Mean Specific Gravity of the Ocean
Fathoms
10 = 1·0250

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60

Track of H.M.S. Challenger shown thus .....

100 FATHOMS=1·0260

Map 8

Arctic Circle

100 Fathoms
500 "
1000 "
1500 "
2000 "
3000 "
4000 "

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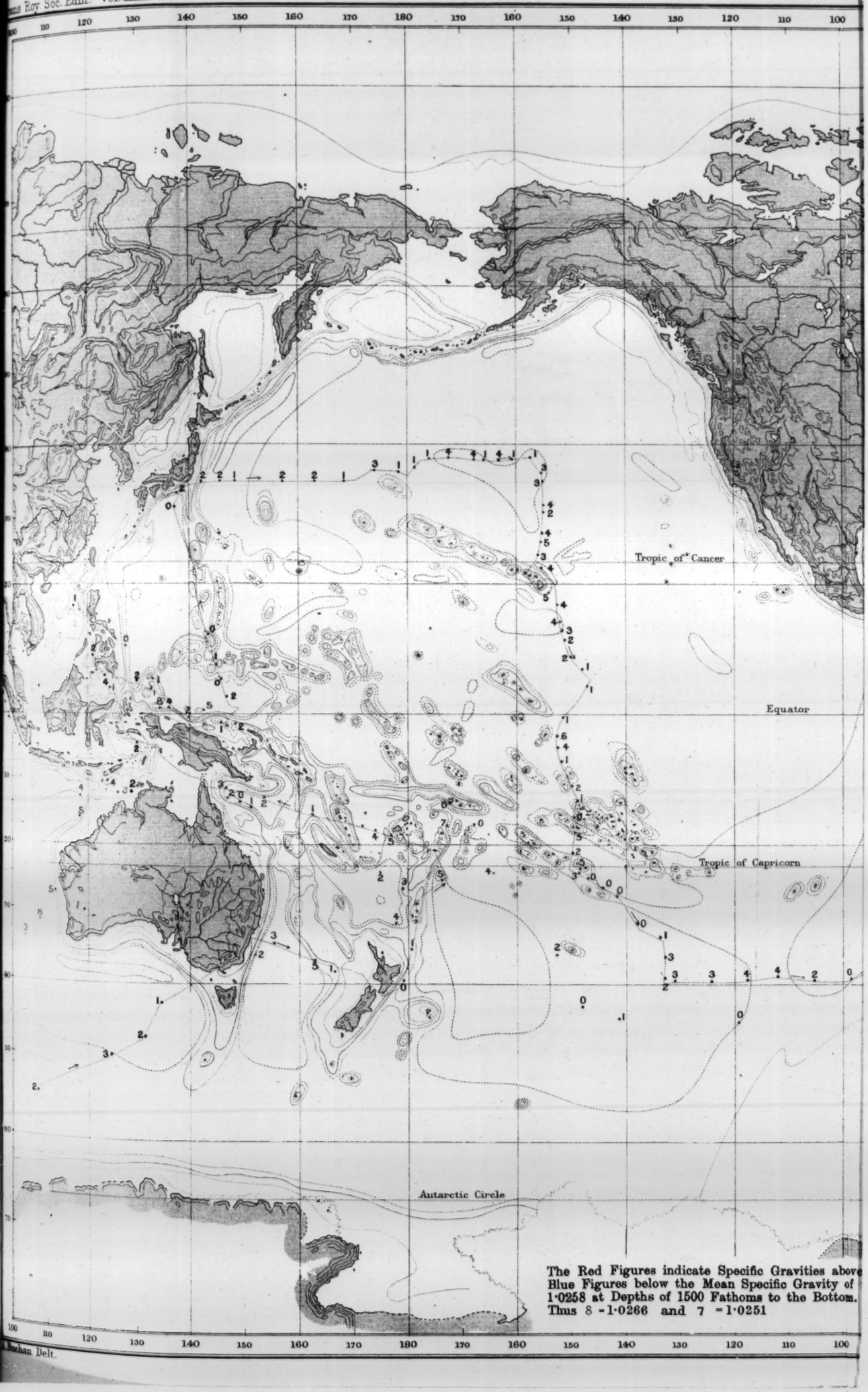
MEAN SPECIFIC GRAVIT



MEAN SPECIFIC GRAVITY OF THE OCEANS, $S\left(\frac{60°}{39°2}\right)$ AT DEPTH OF 1500 FATHOMS TO THE BOTTOM = 1·0258

Arctic Circle

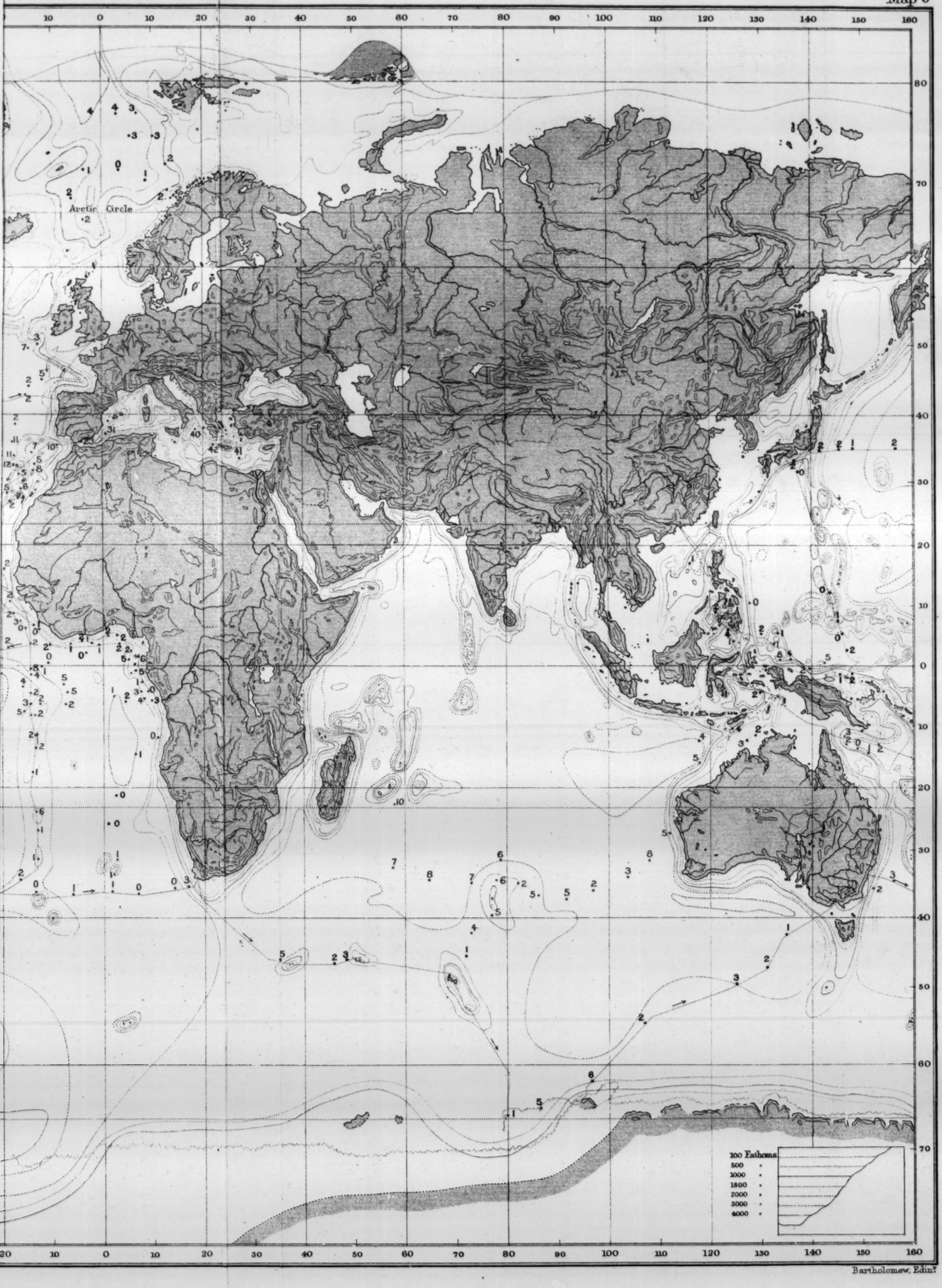
Tropic of Cancer

Equator

Tropic of Capricorn

dicate Specific Gravities above, and the
the Mean Specific Gravity of the Ocean
1500 Fathoms to the Bottom.
d 7 = 1·0251

Track of H.M.S. Challenger shown thus .....



Bartholomew, Edin.r

X.—*On the Deep and Shallow-water Marine Fauna of the Kerguelen Region of the Great Southern Ocean.* By John Murray, D.Sc., LL.D., Ph.D., of the Challenger Expedition. (With a Map.)

CONTENTS.

	PAGE
Introduction,	343
List of Metazoa procured by the Challenger in the deep-water area of the Kerguelen Region, in depths exceeding 1260 fathoms,	353
List of Metazoa procured by the Challenger in the other deep-water areas of the Southern Hemisphere south of the Tropics, in depths exceeding 1000 fathoms, excluding those from the deep-water area of the Kerguelen Region,	378
Total number of Metazoa procured by the Challenger in the Southern Hemisphere south of the Tropics, in depths exceeding 1000 fathoms,	401
List of Metazoa procured by the Challenger in intermediate depths between 150 and 1000 fathoms, in the Kerguelen Region,	403
List of Metazoa procured by the Challenger in shallow water, in depths of less than 150 fathoms, in the Kerguelen Region,	412
List of Metazoa recorded from the Kerguelen Region, from sources other than the Challenger Expedition,	443
Lists of identical and closely-allied species found in the extra-tropical regions of the Northern and Southern Hemispheres, and unknown hitherto within the tropics,	451
List of the Foraminifera observed in the deposits from the Kerguelen Region at various depths,	458
List of the Radiolaria observed in the deposit and on the surface at the Challenger Station 157 in the Southern Indian Ocean,	468
List of the Diatoms observed in the deposits and on the surface in the Kerguelen Region,	472
List of surface organisms recorded during the cruise of the Challenger in the Kerguelen Region,	477
Recapitulation,	482
Concluding Remarks,	487
Explanation of the Map, showing the temperature of the Ocean at 1000 fathoms, and at the bottom in depths greater than 1000 fathoms,	498

Introduction.

During her famous circumnavigation of the world, H.M.S. Challenger left the Cape of Good Hope on the 17th December 1873, and, proceeding in a south-easterly direction, visited in succession Prince Edward and Marion Islands, the Crozet Islands, Kerguelen Island, and Heard Island. From Heard Island the Expedition sailed southward, and on the 16th February 1874 passed ten miles beyond the Antarctic Circle in longitude 78° 22′ E., the ship being at this time surrounded by a large number of huge tabular icebergs, some of them four miles in length, and all with perpendicular sides rising about 200 feet above the sea-level. From this most southerly point the Challenger took a north-easterly course towards Melbourne in Australia, where she arrived on the 17th March 1874.

Throughout this cruise to the Antarctic Regions the Expedition made a very large number of observations on the meteorological, physical, chemical, and biological conditions of the Great Southern Ocean. In this communication it is proposed to deal chiefly with the biological results, and more especially with the biological results obtained in the deep water and shallow water trawlings and dredgings of this region of the

Southern Ocean to the south of the Indian Ocean, which may for shortness be called the Kerguelen Region. The animals captured in the eight deep trawlings between 1260 fathoms (2304 m.) and 2600 fathoms (4755 m.) are peculiarly interesting, because they represent the most southerly positions at which organisms have been procured from the deep sea; and further, because this group of deep trawlings and dredgings has turned out to be more productive than any similar group of Stations during the whole voyage with regard to the number of genera and species obtained from deep water.

Complete lists of the genera and species of Metazoa captured at these deep-water Stations, as well as of the genera and species obtained in the other trawlings and dredgings in deep water over 1000 fathoms south of the southern tropic, are given in this paper, and an examination of what is known of their distribution in other regions of the deep sea brings out some interesting results. Lists of the Metazoa captured in the dredgings and trawlings in intermediate depths between 1000 fathoms (1829 m.) and 150 fathoms (274 m.), and in shallow water in depths less than 150 fathoms around the oceanic islands of the Kerguelen Region, are likewise presented in the paper, and the distribution of the species is analysed with some detail. Our knowledge of the marine fauna of the Kerguelen Region is almost entirely derived from the trawlings and dredgings of the Challenger Expedition; the few additions to our knowledge from other sources are collected in a supplementary list.

In addition to these lists of the Metazoa, lists of the Foraminifera in the deposits, and of the Radiolaria and Diatoms in the deposits and at the surface of the sea, together with notes on the general results obtained by means of the surface nets while the Challenger was engaged in the investigation of the region, are brought together in the concluding portion of the paper. In the map accompanying this paper the temperature of the ocean at a level of 1000 fathoms, and on the bottom in greater depths, is shown, as well as the position of the eight dredging and trawling Stations in the deep-water area of the Kerguelen Region, and the other twenty-nine Stations south of the southern tropic.

Sir Wyville Thomson and the other naturalists of the Challenger were very much struck by the general resemblance of the animals captured in the trawlings and dredgings at moderate depths, in the temperate and colder regions of the Southern Hemisphere, to those they had been accustomed to procure under similar conditions off the coasts of Great Britain and Norway. In the reports of the specialists who have examined the collections from Kerguelen and the other islands of the Southern Ocean, very frequent reference is made to the identical or closely allied species which occur in the colder waters of the Northern and Southern Hemispheres, but have not as yet been recorded from the intervening tropical regions, either in shallow or in deep water. If there be, as indeed seems to be proved by the following investigations, very few widely distributed, or rather universally distributed, species in the deep sea, and if there be a large number of identical and closely allied species in the colder waters of the two hemispheres, wholly separated from each other by

the tropics; if, in short, the marine faunas towards either pole are genetically more closely related to each other than to any intervening fauna, then we are face to face with one of the most remarkable facts in the distribution of organisms on the surface of the globe. A study and comparison of Arctic and Antarctic marine faunas and floras seem indeed to lead directly to very important suggestions as to the past history of the earth and the gradual evolution to the physical and biological conditions which now prevail over its surface.

But apart altogether from the interesting questions here mooted, it is important at the present time, when there is a prospect of a renewal of Antarctic exploration, to summarise our knowledge of the marine fauna of the far south, and to point out the interesting scientific results that would likely flow from a thorough exploration of these regions with modern appliances. However, before proceeding to deal with the biological observations of the Challenger Expedition during the cruise to the Antarctic Regions, it is desirable to recapitulate briefly the present state of our knowledge concerning the geographical, bathymetrical, and physical conditions of the Great Southern Ocean.

The Great Southern Ocean.

Position and Extent.—The name Great Southern Ocean is usually given by geographers to that great belt of water surrounding the world in the Southern Hemisphere between the parallels of 40° S. and the Antarctic Circle (66° 30′ S.). The most important land mass interrupting this continuous band of water is the southern end of South America, which extends as far south as 56° S. The South Island of New Zealand, Tasmania, Kerguelen, and numerous smaller oceanic islands, are also situated within the limits of this great circumpolar ocean.

The boundaries are wholly imaginary and artificial, and are not marked off by any natural features on the surface of the planet; still for convenience of description artificial boundaries are most useful. The Great Southern Ocean is then broadly divided into three regions, merging on their northern limits into the South Atlantic, the South Pacific, and the Indian Ocean. On its southern limit the Great Southern Ocean merges into the ice-bound Antarctic Ocean, situated to the south of the Antarctic Circle.

The area of the Southern Ocean is estimated at about 26,158,850 square miles (67,749,800 square kilometres), or about 18 per cent. of the total water-covered surface of the earth.

Depth.—On either side of the parallel of 40° S. we have a large number of trustworthy soundings extending right around the world, and an examination of these shows that at its northern limit the Southern Ocean has an average depth of about 2300 fathoms (4206 metres) or 2½ English miles. Southward of this line of soundings our knowledge of the depth of the Southern Ocean is very scanty. During her Antarctic trip the Challenger obtained 11 soundings in depths exceeding 1000 fathoms (1829 metres), the depths ranging from 1260 to 2600 fathoms (2304 to 4755 metres). Five of these

soundings were situated towards the Antarctic Circle. Three other soundings greater than 1000 fathoms are recorded to the south of the 60th parallel of south latitude. Ross obtained many soundings in depths ranging from 190 to over 600 fathoms (347 to 1097 metres) to the east of Victoria Land and off the Ice Barrier within the Antarctic Circle. Again, in long. 15° W., within the Antarctic Circle, Ross paid out 4000 fathoms (7315 metres) of line without reaching bottom, so that there is probably a great depth in this position. WILKES obtained depths of 800 and 500 fathoms (1463 and 914 metres) off Adelie Land.

With the exception of several deep soundings where no bottom was found, this is all we know about the depths in the Southern and Antarctic Oceans. The indications, on the whole, point to a gradual shoaling of the sea-bed from the 40th parallel southwards towards the shores of the Antarctic Continent, situated at some points close to the Antarctic Circle, for instance at Wilkes Land. In some places, however, the sea-bed rises into somewhat shallow plateaus, as around Kerguelen and other oceanic islands, and in other places sinks to great depths, as in the Ross Deep and Barker Basin.[1]

Marine Deposits on the Sea-floor.—Nearly all the information we have as to the deposits on the sea-bed near to or within the Antarctic Circle is derived from the observations of the Challenger Expedition, together with a few additions from the Ross and WILKES Expeditions. At her most southerly soundings and dredgings the Challenger procured a Blue Mud made up chiefly of detrital matter from the Antarctic Continent. Imbedded in these muds were large and small fragments of granites, quartziferous diorites, schistoid diorites, amphibolites, mica schists, grained quartzites, sandstones, compact limestones, and partially decomposed earthy shales. These rock fragments were evidently transported from the Antarctic Continent by the icebergs, and their lithological character leaves no doubt that true continental land, and not a group of volcanic islands, is situated within the Antarctic Circle. These rocks were most abundant in the Challenger's dredgings on the Blue Mud at the most southerly stations, but they were met with in diminished numbers in all the dredgings within the area of the ocean affected at times by floating ice from the Antarctic Seas.[2] Although we have very few observations as to its geographical extension, still, judging from what occurs off other continental shores, we may feel sure that the Blue Mud extends all round the Antarctic Continent to a distance of about 200 miles (322 kilometres) seawards.

To the north of the Blue Mud the sea-floor is occupied by a white or cream-coloured deposit chiefly made up of the silicious frustules of Diatoms, with a large admixture of Radiolarians and Sponge spicules. In some places this Diatom Ooze extends north nearly to the 40th parallel. But about the 50th parallel it appears to be usually replaced by a

[1] See Charts in a Summary of the Scientific Results obtained at the sounding, dredging, and trawling Stations of H.M.S. Challenger, 1895.

[2] This view as to the origin of these continental rocks is supported by the facts that D'URVILLE found a rocky islet off Adelie Land, to be composed of gneiss and granite, that WILKES found, on an iceberg in the same locality, boulders of red sandstone, and that Mr BORCHGREVINK, who landed at Cape Adair from the whaler "Antarctic" in 1895, brought away fragments of mica-schists and microcline-granite, with quartz, felspar, tourmaline, and garnets.

deposit for the most part composed of the dead shells of pelagic Foraminifera—the well-known Globigerina Ooze. This calcareous deposit appears to form a continuous band right around the world to the north of the Diatom Ooze.

In great depths, however, as for instance to the west of Tasmania in 2600 fathoms (4755 m.), a Red Clay occupies the sea-bed. The peroxides of iron and manganese make up a large part of this Red Clay, and in it are embedded manganese nodules, zeolitic crystals, magnetic spherules with metallic nuclei of extra-terrestrial origin, thousands of sharks' teeth, ear-bones and other bones of whales or other Cetaceans. The Red Clay deposit with all these special characteristics is especially well developed on the northern limits of the Great Southern Ocean in the Pacific. In the composition of all these deposits the physical conditions of the surface waters are reflected. The Blue Muds with abundant boulders indicate a sea very frequently covered with floating icebergs. The Diatom Ooze indicates cold surface water of a low specific gravity, and with clayey matter in suspension. The Globigerina Ooze indicates the warmer water of the temperate regions with numerous pelagic organisms having calcareous shells and skeletons, such as Coccospheres, Foraminifera and shelled Molluscs.

Meteorology.—There is a wide range of temperature of both the air and sea-water within the limits of the Great Southern Ocean. In the neighbourhood of the Antarctic Circle the temperature of the air and sea-surface is, even in summer, at or below the freezing-point of fresh water. Direct observations have, in these latitudes, only been made during the summer, so that we have no certain knowledge of the air temperature during the winter months, nor of the annual range of temperature. In all probability the range of the water temperature at the Antarctic Circle throughout the year is not greater than three or four degrees Fah. (about two degrees Cent.), and the sea in these latitudes must always be burdened with floating ice. Indeed, with the exception of an area to the south of Australia and New Zealand, the whole area of the Southern Ocean may be occasionally affected with floating ice from the Antarctic Continent; the extreme limit within which drift ice has been observed extends to the north of the 40th parallel of south latitude in the Atlantic, and nearly to this parallel at some points of the Pacific and Indian Oceans.

At the northern limits of the Southern Ocean on the 40th parallel south there is a wide annual range of temperature, both of the air and of the sea-surface. At some points the range is over 50° F. (about 28° C.) in the case of the air, and over 31° F. (about 17° C.) in the case of the water, for instance, off the Agulhas Bank. These great variations in the temperature of the sea-surface are brought about chiefly by a mixture of oceanic currents from a tropical source on the one hand and from a south polar source on the other. One result of this mixture of currents from different sources is the destruction of large numbers of pelagic organisms in the surface waters of the Southern Ocean, and these, falling to the bottom, provide abundant food for the rich deep-sea fauna, which, we shall see, lives on the sea-bed in this region of the ocean.

One of the most remarkable features of the meteorology of the globe is the low

atmospheric pressure at all seasons in the southern hemisphere between the latitudes of 40° and 60° S. Over certain parts of these latitudes—for example to the south-east of the Falkland Islands and to the south-east of New Zealand—the observations hitherto made point to a mean pressure of 29·000 inches (736·6 mm.) and under. To the north of this broad belt of low atmospheric pressure there is, about lat. 30° S., an area of very high atmospheric pressure, and we have many reasons for believing that an area of high pressure rests on the Antarctic Continent in the far south.[1]

The inevitable result of this arrangement of isobars is that strong westerly winds with large rain-fall and snow-fall prevail over nearly the whole area of the Southern Ocean. These "Anti-Trades" blow with great persistency nearly due west, and having an uninterrupted sea space over which to blow they frequently rise to the force of a violent gale, and blow as such for several days in succession. Thus out of sixty-eight days during which Sir JAMES C. Ross lay at Kerguelen, a gale from the north-west is reported on forty-five days. Among sailors the latitudes of these winds are known as the "roaring forties."

Waves and Currents.—The depth of the Southern Ocean and the great extent of open sea over which they blow, enable the strong westerly winds to produce the longest and highest waves anywhere encountered. Thus the "Novara" in 1857 records waves 36·1 feet (11 m.) in height about lat. 40° S., long. 31° E. Lieut. PARIS in 1867 measured six successive waves 37·7 feet (11·5 m.) in height between the Cape of Good Hope and the island of St. Paul's, and the Challenger in 1874 met the highest waves of the voyage, viz., 23 feet (7 m.), between the Crozet Islands and Kerguelen.

A much more profound and far-reaching influence of the westerly winds of the Southern Ocean is the creation of enormous westerly drift currents. These currents are fed by warm and saline water from the tropics, and by cold and less saline water from the south polar area; water must likewise sometimes be drawn towards the surface from the deep layers, and a thorough mixing of the waters appears to take place in these latitudes. So persistent is the action of the westerly winds in the Southern Ocean throughout the year, that their influence appears to be felt right down to the bottom, the density produced by varying degrees of salinity and temperature greatly facilitating this downward movement.

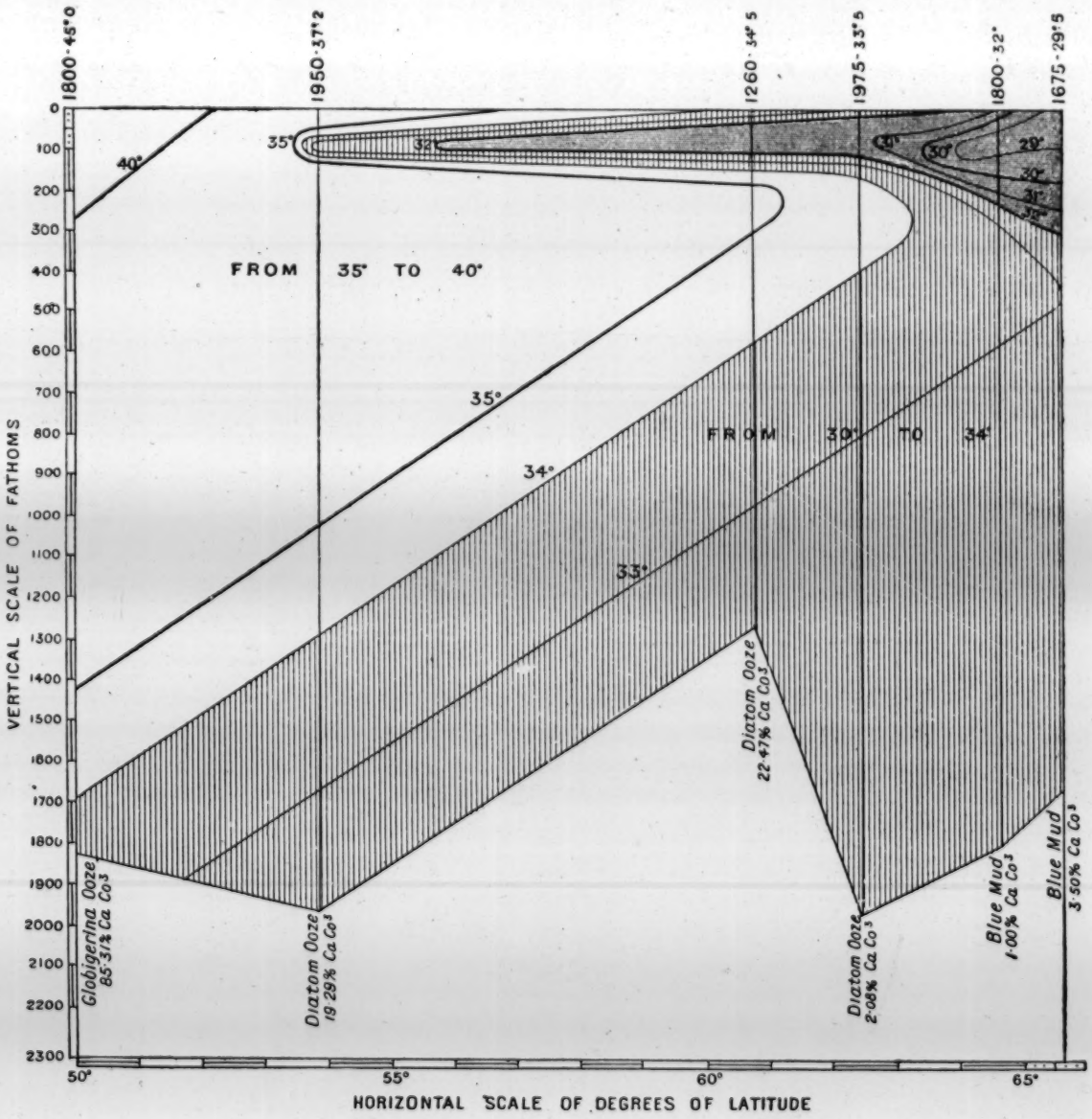
Temperature of the deeper layers of water.—The object of the Challenger's excursion into the Antarctic Regions in 1874 was not to reach a high latitude, but chiefly to make observations on the depth, temperature, and salinity of the ocean in the vicinity of the Antarctic ice. The observations were of the greatest value, although not satisfactory in all respects; they give some hints as to the kind of circulation that takes place, and very clearly demonstrate the urgent necessity for further observations in these regions. In this region of the Antarctic and Southern Oceans there appears to be a cold layer of water sandwiched between a warmer one on the surface and a warmer and thicker one

[1] See MURRAY, "The Renewal of Antarctic Exploration," *Geogr. Journ.*, vol. iii. p. 17, 1894, with map of isobars and winds.

at the bottom. The temperature of the lower warm stratum could not be accurately determined, for the thermometers, being maximum and minimum ones, were unable to record, having passed through a warm layer of 37°·2 F. (2°·89 C.) and a cold layer of 32°·5 F. (0°·28 C.).[1] The general result may be thus stated:—A cold intermediate stratum of water was traced from the Antarctic Circle as far north as 54° S., where its temperature was 32°·5 F. (0°·28 C.) at 80 fathoms (146 m.). Towards the south the

MERIDIONAL TEMPERATURE SECTION

Between the Parallels of 50° and 65° South Lat.



temperature of this cold stratum decreased till at the Antarctic Circle it was 29° F. (−1°·67 C.) from immediately below the surface to a depth of 200 fathoms (366 m.).

[1] Thus we find that at Station 156, 1975 fathoms, the surface temperature was 33°·5, the temperature at 100 fathoms was 31°·9, and at 150 fathoms 34°, and below the depth of 150 fathoms the thermometer came up, showing on the maximum side 34°, and on the minimum side 31°·9; hence it is impossible to say what the precise temperature of the sea was below 150 fathoms: all that can be asserted is that it ranged between 34° and 31°·9.

A wedge of cold water thus stretches northwards from the Antarctic Circle for more than twelve degrees of latitude, being overlaid and underlaid by strata of a higher temperature (see diagram). In the Antarctic Ocean the temperature of the water is probably 28° or 29° F. (−2°·22 or −1°·67 C.) from the surface to the bottom, for the temperature of the lower stratum decreases as colder latitudes are reached. One remarkable fact brought out by these observations is that in latitude 50° S. the bottom water has a temperature of 33°·5 F. (0°·83 C.), which is very little different from the temperature found all over the bottom in the Indian and other Oceans. The tendency in a polar ocean, isolated from general oceanic circulation, is to produce a uniform temperature of about 28° or 29° F., and this is the temperature actually observed in the Norwegian Sea, north of the Wyville-Thomson Ridge, on which the depth is 250 fathoms (457 m.). There is no evidence at the present time of a similar condition of things in the Antarctic or Great Southern Ocean.

Salinity and Density of the Sea.—Mr BUCHANAN'S observations on the density of sea-water, and his experiments on the formation of sea-water ice, throw much light on the causes of the remarkable distribution of temperature noted above. All the observations made on water from the bottom or intermediate depths in the Southern Ocean, with the density of the surface-water at each Station, are brought together in the following table.[1]

Salinity of Water expressed as Density at $S\frac{60°\text{ F.}}{39°{\cdot}2\text{ F.}}$ $\left(S\frac{15°{\cdot}56\text{ C.}}{4°\text{ C.}}\right)$

Depth from which Water was taken.	Station 143. Lat. 36° 48′ S. Long. 19° 24′ E.	Station 144. Lat. 45° 57′ S. Long. 34° 39′ E.	Station 147. Lat. 46° 16′ S. Long. 48° 27′ E.	Station 152. Lat. 60° 52′ S. Long. 80° 20′ E.	Station 153. Lat. 65° 42′ S. Long. 79° 49′ E.	Station 154. Lat. 64° 37′ S. Long. 85° 49′ E.	Station 156. Lat. 62° 26′ S. Long. 95° 44′ E.	Station 157. Lat. 53° 55′ S. Long. 108° 35′ E.	Station 158. Lat. 50° 1′ S. Long. 123° 4′ E.	Station 159. Lat. 47° 25′ S. Long. 130° 32′ E.	Station 160. Lat. 42° 42′ S. Long. 134° 10′ E.
Surface, . . .	1·02657	1·02516	1·02515	1·02512	1·02413	1·02458	1·02508	1·02509	1·02522	1·02566	1·02570
50 fathoms, . .	629	...	...	...	...	534	...	507	522	...	576
100 ,, . .	616	524	512	...	...	(140 faths.) 1·02547	561	537	544	...	565
200 ,, . .	593	533	535	...	...		565	...	548	...	573
300 ,, . .	572	532	534	...	...	558	565	...	(315 faths.) 1·02546	...	560
400 ,, . .	579	537	536	...	...	562	555	...	...	...	557
Bottom, . . .	607	525	550	1·02561	1·02567	529	515	561	554	1·02564	570
Depth of bottom (fathoms), . .	1900	1570	1600	1260	1675	1800	1975	1950	1800	2150	2600

It will be observed that the salinities in the first column in lat. 36°48′ S. are higher than in any other column; the water from surface to bottom bears evidence of having been warmed and concentrated in tropical or sub-tropical regions, the position being where the warm water of the Indian Ocean is carried southwards of the Cape of Good Hope. The salinities of all the other columns are from stations within the zone of

[1] See Challenger Report, Summary of Results, First Part, *passim*.

southern icebergs, and it will be observed that the salinity of the surface water decreases as a colder latitude is approached, and that, generally speaking, there is a rise of salinity with increase of depth. It is therefore probable that the bottom water in the deeper regions of the Southern Ocean is a mixture of water cooled to a low temperature in these regions with water of a higher temperature drawn in, or driven in, from a warmer latitude.

The effect produced on a sea when its surface is frozen over is an important consideration in discussing these relations of temperature and density. Sea-water ice is composed of a mixture of ice, salt crystals, and mechanically inclosed brine, so that ocean water is divided by freezing into two saliniferous parts—one liquid, one solid—which are of different chemical compositions, a striking feature of the freezing process being that the mixture of ice and salt crystals is richer in sulphates than the brine, while the brine is richer in chlorides. In the act of freezing, then, the sea-water separates into ice which contains less salt and into brine which contains more salt than the parent sea-water, and it may be assumed that both the ice and brine have the same temperature (29° F.). The brine being denser than the surrounding water, sinks into it, and by mixing with it renders it more salt and slightly different in composition from the original water, and, at the same time, lowers its temperature.

Circulation of Ocean Water.—In the portion of the Southern Ocean traversed by the Challenger, the soundings show that there is only a very slight and gradual shoaling from the Indian Ocean towards the Antarctic Circle. Hence there is no impediment to the free circulation of the water between cold and warm latitudes. The effect of the winter cold in the far south is in one respect the same as that of heat in tropical regions —it removes water from the sea and thus produces concentration. In the tropics the water is removed as vapour; in the polar regions it is removed as ice, leaving a salter water, at the freezing temperature of the sea-water, which sinks and cools the deeper water by convection. In summer, when the ice breaks up, some of it melts and forms a layer of less saltness but low temperature at the surface. This layer, along with the melting pack-ice and icebergs floating in it, is generally driven in part far to the northward of the place where it was formed. Its place must be supplied from below by water coming from more northerly latitudes, unless the supply of land ice from the Antarctic Continent were sufficient to supply the deficiency.

In the Atlantic, Indian, and Pacific Oceans the return currents of dense warm tropical water which run southward along the eastern shores of South America, Africa, and Australia, penetrate southwards into the region of the Great Southern Ocean, and the effect of these currents can evidently be traced in the distribution of the southern ice at its northern limits. The water of these currents has such a high salinity that it can bear much dilution and still sink through the water of cold latitudes at the same temperature. It is very probable, therefore, that the cold water of the bottom of the ocean within the tropics mostly comes from the Southern Hemisphere, and leaves the surface between the parallels of 42° and 56° of south latitude. From this zone the water is drawn northward

over the ocean's floor to make good the deficiencies caused in the tropics by surface currents and evaporation, and there can be little doubt that it also flows southward to supply the place of the ice and cold surface water drifted northward. The comparatively warm water which reaches the Antarctic Circle at depths greater than 200 fathoms probably comes also from this zone between 42° and 56° S. lat., its temperature being, of course, lowered by being drawn into polar areas.

If there were in the Antarctic Ocean basins like that of the Norwegian Sea, cut off by submarine ridges from general ocean circulation, the water in these basins would have the same low temperature of 29° F. from surface to bottom. The brisk superficial circulation which is kept up in the Arctic Ocean by the extension of the Gulf Stream waters along the coast of Norway, and the return of the cold polar currents removing ice by the eastern coast of Greenland and Baffin's Bay, results in that ocean being comparatively open to a very high latitude, and produces at the same time a great depth of relatively warm and saline water along the northern coasts of Norway. A similar circulation appears to be entirely wanting in the Antarctic Seas; hence their ice-bound character.

The mean of the eighteen surface salinities observed by the Challenger to the south of lat. 60° S. is 1·02475 ($S_{39°\cdot2}^{60°}$), and of the six furthest south of these the mean is 1·0245. This is the same as MOHN's line of lowest salinity between Greenland and Spitzbergen. Nothing was observed, however, so low as 1·0240 found by Admiral MAKAROFF in the southern part of the Sea of Okhotsk.

We have already pointed out that, owing to the mixture of cold and warm waters in the upper layers of the Southern Ocean, large numbers of pelagic marine organisms are killed, and their bodies, falling to the bottom, afford abundant food for the deep-sea animals of this region, and thus have a determining influence on the richness of the Benthos fauna. The abundance of food, however, is not the only condition favourable to animal existence, for the physical condition of the water renders it peculiarly fit for the support of animal life. Owing to the low temperature of the surface, the dissociation tension of the atmospheric gases in solution is very low. In order, therefore, to come into equilibrium with the atmospheric pressure, the water takes up a correspondingly large quantity of atmospheric gases, particularly oxygen. This cold, and therefore heavy, water sinks down, carrying with it to the lower strata its store of oxygen. This unusually copious supply of oxygen cannot but have an important influence on the life at great depths in these regions.

Colour of the Water.—The colour of the sea varies considerably throughout the Southern Ocean, sometimes being a deep blue, but in the neighbourhood of the ice it is often green or brown-coloured, due to the presence of Diatoms or other marine Algæ. The lower forms of Crustacea are occasionally so numerous as to give the water a reddish tinge.

LIST I.

METAZOA PROCURED BY THE CHALLENGER IN THE DEEP-WATER AREA OF THE KERGUELEN REGION, IN DEPTHS EXCEEDING 1260 FATHOMS.

This list contains all the species and varieties of marine Metazoa described and recorded in the Challenger Report from eight deep-water Stations in the Great Southern Ocean, south of the Indian Ocean, traversed by the Challenger during the cruise from the Cape of Good Hope to the Antarctic Circle and Australia, viz., Stations Nos. 146, 147, 152, 153, 156, 157, 158, and 160, lying between latitude 42° 42′ to 65° 42′ S. and longitude 45° 31′ to 134° 10′ E., the depths varying from 1260 fathoms at Station 152 to 2600 fathoms at Station 160. For the sake of brevity this region has been called the deep-water area of the Kerguelen Region. At the most southerly Station (No. 153) the dredge was used, the trawl being sent down at the other seven Stations. The species not known to occur outside the region represented by these eight Stations, nor therefore in depths less than 1000 fathoms, are indicated in this list by an asterisk *.

MONAXONIDA :

Axinella erecta [1] (Carter).
**Cladorhiza* [2] *moruliformis*,[3] Ridley and Dendy.
* ,, (?) *tridentata*,[4] Ridley and Dendy.
**Esperella mammiformis*,[5] Ridley and Dendy.
**Esperiopsis* [6] *profunda*,[7] Ridley and Dendy.

[1] *Axinella erecta* is a very variable species.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 182.)

[2] Although the different species of *Cladorhiza* vary very much in external form, yet the different modifications of the main skeleton, upon which the external form of the sponge depends, are easily derivable from one common primary type, and afford interesting instances of adaptation.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 86.)

[3] *Cladorhiza moruliformis* is a form of the very greatest interest, and affords a good example of radial symmetry in a Monaxonid Sponge. It was a question with us whether or not this species should form the type of a new genus, but we finally decided not, as no essential changes are necessary to derive it from the more typical species. . . . It is, of course, by no means impossible that perfect specimens of *Cladorhiza moruliformis* may have a branching stem with a head at the end of each branch.--(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 91, 92.)

[4] In the arrangement of its skeleton *Cladorhiza tridentata* stands quite alone in the genus, and as this is generally such a good guide, it seems very doubtful whether it ought to be admitted as a *Cladorhiza*, but for the sake of convenience we shall retain it here for the present, placing it at the end as a doubtful species.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 96.)

[5] *Esperella mammiformis* is a very beautiful little species, and affords another good example of a deep-sea sponge with a definite external form.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 63.)

[6] Several of the species of the genus *Esperiopsis* are remarkable for their well-defined external forms, which serve as excellent guides by which to separate them from one another and from others of the genus. . . . The distribution of the genus *Esperiopsis* is very wide, both vertically and horizontally, but it appears to prefer deep water in temperate or boreal seas.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 77.)

[7] *Esperiopsis profunda* is interesting on account of the great depth (1600 fathoms) from which it was obtained, and with this must again be associated the presence of a definite external form.—(RIDLEY and DENDY, *Zool. Chall Exp.*, part 59, p. 84.)

**Meliiderma stipitata*,[1] Ridley and Dendy.
Stylocordyla[2] *stipitata* (Carter).

TETRACTINELLIDA :

**Thenea*[3] *delicata*, Sollas.

HEXACTINELLIDA[4] :

Aulocalyx irregularis,[5] Schulze.
**Balanella pipetta*, Schulze.
**Bathydorus spinosus*, Schulze.
**Caulophacus latus*,[6] Schulze.
Farrea sp. (?).
**Holascus fibulatus*, Schulze.
* ,, *polejævii*, Schulze.
**Hyalonema conus*, Schulze.
* ,, (*Stylocalyx*) *clavigerum*, Schulze.
**Malacosaccus vastus*, Schulze.
**Pleorhabdus oviformis*, Schulze.

[1] The genus *Meliiderma* stands in much the same relation to *Chondrocladia* as does *Axoniderma* to *Cladorhiza*, having, like *Axoniderma*, developed a special spicule for external defensive purposes. The form of the extra spicule is, however, totally different in the two cases ; and in *Meliiderma* it appears to be confined to the stalk, while in *Axoniderma* it is most abundant in the body of the sponge. In both these cases it is very difficult to say whether the extra spicule ought to be classed amongst megasclera or microsclera ; for the sake of convenience both will here be regarded as microsclera, though standing on quite a different footing from other microsclera. The form of the extra microsclera in *Meliiderma stipitata* is as yet unparalleled. From their resemblance to spears or darts we have derived the generic name. . . . Only one perfect specimen of this sponge and one damaged one are in the collection ; in both of these the stalk is encrusted by a thin, yellow, velvet-like layer of the densely packed, spear-like spicules. At first we thought that these spicules belonged to some foreign encrusting sponge, and hence no mention of them was made in our Preliminary Report, but subsequent examination has convinced us that they are proper to the species ; the fact of their occurring in both specimens being strong evidence in favour of this view. An interesting point about the sponge is the position in which the embryos develop. In the specimen which we cut open a number of round yellow bodies were found, each enclosed in a membranous capsule around which the chelate spicules were lying in very great numbers. These embryos were placed in a zone of tissue occupying about the centre of the spherical head, and lying immediately above the expanded termination of the stalk, between the bands of spiculo-fibre which radiate from it ; this being obviously the position of greatest security.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 102, 103.)

[2] The genus *Stylocordyla* still stands aloof from all other Suberitidæ in its remarkable spiculation, though, as regards external form, the old distinction embodied in the term *Stylocordyla* no longer holds good, for similar stipitate forms are found to occur in the genus *Suberites*. . . . The external form of this sponge is very variable. SCHULZE, as well as CARTER, has already noticed that the head in young forms is more or less round ; we have to notice below a variety in which the head is globular even in the adult.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 222, 223.)

[3] The genus *Thenea* is the characteristically deep-water genus of the Tetractinellida, the shallowest water from which it has yet been recorded being 78 fathoms, the deepest 1913 fathoms.—(SOLLAS, *Zool. Chall. Exp.*, part 63, p. 404.)

[4] It is a striking fact that [among the Hexactinellida] the Asconematidæ, which occur somewhat abundantly in the south temperate zone, and likewise in the north, are represented in the tropics only by a single species.—(SCHULZE, *Zool. Chall. Exp.*, part 53, p. 449.)

[5] *Aulocalyx irregularis* appears to be widely distributed, since it was found both in the north and south temperate zones.—(SCHULZE, *Zool. Chall. Exp.*, part 53, p. 450.)

[6] *Caulophacus latus* was found in the south temperate zone, the other species, *Caulophacus elegans*, far removed in the northern region.—(SCHULZE, *Zool. Chall. Exp.*, part 53, p. 450.)

ALCYONARIA :

**Callozostron mirabilis*,[1] Wright.

PENNATULIDA[2] :

**Umbellula carpenteri*,[3] Kölliker.
* ,, *magniflora*, Kölliker.

ANTIPATHARIA :

**Bathypathes tenuis*, Brook.

ACTINIARIA[4] :

**Bunodes minuta*, Hertwig.
Cereus spinosus, Hertwig.

[1] The axis in the imperfect specimen dredged of this deep-sea form [*Callozostron mirabilis*] is about 280 mm. in length, it is extremely flexible, and nearly 20 mm. in widest diameter. The colony strongly reminds one at first sight of some gigantic Annelid. . . . It seems probable that this species lived prostrate in the mud, and possibly there may have been some power of expansion and contraction in the colony. It was dredged in the most southern station reached by the Challenger.—(WRIGHT and STUDER, *Zool. Chall. Exp.*, part 64, pp. 48, 49.)

[2] It follows from all these facts that the simpler forms of the Pennatulida, especially those with sessile polyps, inhabit great depths. The presence of their less complex representatives in deep water has also been shown in other invertebrate groups. These simpler forms are probably also the oldest, and may be regarded as the last remnants of an extinct primary creation. The Protoptilidæ and the Umbellulidæ are the principal representatives of these old forms, and of these two families especially the Challenger Expedition has discovered a large number of species with a wide distribution. This addition to our knowledge makes it possible to gain a better insight than formerly into the development of the whole group.—(KÖLLIKER, *Zool. Chall. Exp.*, part 3, p. 39.)

[3] The five specimens of *Umbellula carpenteri* showed a very interesting gradation from a bilateral to an apparently irregular arrangement of the polyps. One specimen had one terminal and two lateral polyps; another specimen had four polyps, all lateral; a third specimen had one terminal polyp, two lateral on the right and one only on the left side; in a fourth there were eight polyps, of different sizes, so disposed that they formed a rosette surrounding a small dorsal area of the rachis of a stellate form, but amongst these polyps the terminal one was easily recognisable, as the axis ended in its base, and the other seven could be interpreted as lateral polyps arising from a shortened rachis; the fifth specimen finally showed eight polyps, arranged in the form of a rosette, and surrounding like a cup a ninth middle polyp, but this was not the terminal one in which the axis ended, one of the eight had this signification.—(KÖLLIKER, *Zool. Chall. Exp.*, part 3, pp. 23–4.)

[4] The varying character of the deep-sea fauna leads us to the question, has life in the great depths a visible influence on the organisation of the Actiniæ? This influence can be distinctly recognised in many forms, and is shown by the nature of the tentacles which have undergone retrograde formation, and are transformed first into tubes, and afterwards into simple openings in the oral disk. In *Paractis tubulifera* (1875 fathoms) the tentacles have the same constitution as in the majority of Actiniæ, except in one point, that the terminal opening, which is usually small or entirely wanting, gapes widely. In *Polysiphonia tuberosa* (565 fathoms) the tentacles have become short, slightly movable, wide-mouthed tubes; in *Sicyonis crassa* (1600 fathoms) they are small wart-like rings, and in *Polystomidium patens* (1825 fathoms) and *Polyopis striata* (2160 fathoms) the walls have almost entirely disappeared, so that the terminal opening forms a fissure in the oral disk, the last remains of the tentacle being represented by a circular margin surrounding the fissure, and so we come finally to the genus *Liponema* (1875 fathoms), in which the points at which the tentacles were actually placed are merely indicated by openings in the oral disk. Of the twenty-one forms from 500 to 3000 fathoms here described, no less than six species have therefore undergone modifications of the tentacles in the same sense, whilst it has never been observed in a single one of the forms of the coast fauna, which greatly exceed the deep-sea fauna in number. . . . There is another point in the mode of life of the deep-sea Actiniæ which seems to me to favour the transformation of the tentacles into tubes and openings. The nutriment of the deep-sea animals probably consists chiefly of material which is already disintegrated, and of a soft nature when obtained. The animals often ingest sand, impregnated with nutriment, from which they extract what is digestible; at least I have repeatedly found the interior of the deep-sea Actiniæ full of mud. In such a mode of nutrition the long prehensile tentacles would not be of the same use as they are in the littoral Actiniæ, which lie in wait for booty, whilst on the other hand it would

Corallimorphus obtectus, Hertwig.
„ *rigidus*, Moseley.
Liponema multiporum,[1] Hertwig.
Porponia elongata,[2] Hertwig.
Sicyonis crassa,[3] Hertwig.
Tealidium cingulatum,[4] Hertwig.
Another Actinian undetermined.

CORALS :

Bathyactis symmetrica [5] (Pourtalès).

be a decided advantage to the animals to be furnished with numerous inhalent tubes and openings through which they can absorb semi-liquid nourishment. This then is the advantage of the stomidia and tubular tentacles. The retrograde formation of the tentacles is by no means the only point to be taken into consideration in the varying character of the deep-sea Actiniæ, the position of the septa being equally important. The arrangement of the septa typical of the Hexactiniæ is only present in thirteen genera, among which I reckon *Ophiodiscus* and *Polystomidium*, in which we meet with the differentiation of muscular and genital septa which is otherwise unknown, and the genera *Stephanactis* and *Amphianthus*, in which we find some approach to the Antipatharia. The other four genera differ from one another as well as from the Hexactiniæ in the arrangement of the septa. They swell the number of the varying forms represented in shallow water by the Zoantheæ, Cerianthеæ, and Edwardsiæ, and therefore seem to indicate that the diversity in the structure of the Anthozoa was formerly much greater than it is at present, and that the remains of this diversity have been more extensively preserved in the depths of the sea than in the shallow waters. In this way we can recognise peculiarities in deep-sea Actiniæ which are common to the whole deep-sea fauna.—(HERTWIG, *Zool. Chall. Exp.*, part 15, pp. 132–134.)

[1] The tentacles in *Liponema multiporum* have undergone retrograde formation to a greater extent than in any other Actinia, as there are not the smallest remains of their walls, while in *Polyopis* these can still be recognised as thickened ridges surrounding the openings.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 129.)

[2] Whilst the majority of Actiniæ, especially those from great depths, form a short column, and are frequently flattened into a disk, the body form of *Porponia elongata*, from 2600 fathoms, approximates that of the elongated Cerianthidæ. In both specimens examined the body, though contracted, was twice as long as high. It is broadest in the region of the oral disk, below which it becomes a little narrower, and then becomes broader again at the pedal disk, by which it is firmly attached to the bottom.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 125.)

[3] *Sicyonis crassa* is one of the most interesting Actiniæ dredged from great depths, both on account of the constitution of the tentacles and of the arrangement of the septa.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 98.)

[4] The single specimen of *Tealidium cingulatum*, which was taken attached to a stone from a depth of 1800 fathoms, belongs to the smallest forms among the Challenger material. It is so strongly contracted that the wall closes over the entrance to the oral disk till only a small opening is left.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 51.)

[5] *Bathyactis symmetrica* was dredged by the Challenger in all parts of the world. It varies very much in size and appearance, the smallest specimens obtained measuring 3 mm. and the largest 40 mm. in diameter ; the increase in size being evidently not a matter of age and growth as of different development under different conditions. . . . The inspection of a long series of specimens leaves no doubt as to the identity of the large specimens with the small ones. The very large specimens are excessively thin and fragile, and only a small percentage of them were obtained in an unbroken condition. . . . The larger specimens vary in very much the same manner as the smaller ; some have the margins of their septa fused for long distances at their points of junction ; others show little fusion of the septal margins. In some specimens the fusion of the septal margins is very irregular, in one a spongy outgrowth is developed from the coverings of one of the deltas. In some of the largest specimens there is scarcely any trace of a columella ; in others there is a large oval one, composed of a membranous expansion, through which the spines project. . . . After tabulating all the occasions on which this coral was dredged, I cannot succeed in establishing any relation between the size of the specimens dredged, and the conditions of depth, bottom, or temperature. No large specimen was dredged in less than from 200 to 360 fathoms, but from one of these depths a broken specimen, which must have measured more than 30 mm. in diameter, was obtained. Small, apparently adult, specimens of the stouter variety, measuring only 9 mm. in diameter, were dredged from such depths as 2440 fathoms on several occasions. The greater number of very large specimens were obtained from deep water, many being brought up at one haul of the dredge, as at Station 147, in the South Indian Ocean, where twenty or thirty specimens were obtained from 1600 fathoms, curiously enough, all of them large, no young ones being found amongst them. *Bathyactis symmetrica* was found to have a wider range

Leptopenus[1] *discus*, Moseley.

HYDROIDA :

**Cryptolaria abyssicola*,[2] Allman.
**Halisiphonia megalotheca*,[3] Allman.
Stephanoscyphus simplex, Allman, MS.

MEDUSÆ :

Atolla wyvillei, Haeckel.
**Pectis antarctica*, Haeckel.
**Periphema regina*, Haeckel.
**Thamnostylus dinema*, Haeckel.

SIPHONOPHORÆ :

**Disconalia pectyllis*, Haeckel.

CRINOIDEA :

Antedon[4] *abyssicola*,[5] Carpenter.

than any other deep-sea coral, being, in fact, apparently universally distributed in deep water. It has also a wider range in depth than any other animal, occurring in 30 fathoms off Bermuda, and in the East Pacific Ocean at a depth of 3 miles. It was dredged abundantly at Station 244, 2900 fathoms, the specimens being large and in full vigour, full of ripe ova. Some specimens appear as if they had been broken and had reunited, or possibly they were when obtained in the act of splitting up into fragments, or have a tendency to do so.—(MOSELEY, *Zool. Chall. Exp.*, part 7, pp. 186–188.)

[1] I have founded this genus [*Leptopenus*] to contain two very remarkable corals, dredged in deep water, which are so fragile that it is astonishing that they arrived at the surface in such good preservation as that in which they were obtained. The two species differ markedly from one another, but have so many fundamental agreements that they must evidently be placed in the same genus. They are evidently closely related to the Stephanophyllias, but their corallum is so perforate as to be reduced to a mere lace-work. No corals immediately like them appear to have been procured before, or since, either in the recent or fossil condition. Specimens belonging to the genus were dredged on four occasions, all from deep water (over 1500 fathoms), and all in the Southern Hemisphere.—(MOSELEY, *Zool. Chall. Exp.*, part 7, p. 205.)

[2] The vast depth from which *Cryptolaria abyssicola* has been dredged (2600 fathoms) gives it a special interest, which is greatly enhanced by the fact that it affords one of the very few instances as yet known in which the gonosome of *Cryptolaria* has been detected. The scattered instead of distichous disposition of the hydrothecæ is a peculiar and exceptional character.—(ALLMAN, *Zool. Chall. Exp.*, part 70, p. 40.)

[3] The genus *Halisiphonia* is represented in the Challenger collection by a single species, which presents many points of special interest. . . . The very long tubular hydrothecæ gradually passing into their long peduncles confer on this remarkable species [*Halisiphonia megalotheca*] an aspect as striking as it is distinctive. . . . The enormous depth of 2600 fathoms from which both *Halisiphonia megalotheca* and *Cryptolaria abyssicola* were obtained has much significance, in connection with the fact that in both species the gonangia are present, *Halisiphonia megalotheca* affording the only known instance, and *Cryptolaria abyssicola* one of the very few, in which any part of the gonosome has been observed in these genera.—(ALLMAN, *Zool. Chall. Exp.*, part 70, p. 31.)

[4] In discussing the distribution of *Antedon* and *Actinometra*, the two principal genera of Comatulæ, it must be remembered that each of them, but especially *Antedon*, contains a very large number of species, and they should be considered for this purpose to represent subfamilies rather than genera. Thus, for example, the name *Antedon* is now given to all endocyclic Comatulæ with the basals metamorphosed into a rosette, and five rays bearing ten or more arms, just in the same way as the name *Echinus* was originally used for a variety of regular Urchins, which have now received different generic names. The difference between the tiny ten-armed *Antedon abyssicola* inhabiting depths of 3 miles and upwards, and the littoral *Antedon elegans*, *Antedon multiradiata*, or *Antedon regalis*, is no doubt very considerable at first sight ; but there are so many intermediate links between the simple and the complex forms, that no hard and fast generic lines can be drawn.—(P. H. CARPENTER, *Zool. Chall. Exp.*, part 60, p. 31.)

[5] This little species [*Antedon abyssicola*] is one of very considerable interest, apart altogether from the peculiarities

**Antedon abyssorum*, Carpenter.
* „ *bispinosa*,[1] Carpenter.
* „ *remota*, Carpenter.
Bathycrinus[2] *aldrichianus*, Wyville Thomson.
Hyocrinus bethellianus, Wyville Thomson.
**Promachocrinus abyssorum*, Carpenter.
**Thaumatocrinus renovatus*, Carpenter.

ASTEROIDEA :

**Brisinga discincta*, Sladen.
* „ *membranacea*, Sladen.
**Chitonaster cataphractus*, Sladen.
**Freyella*[3] *fragilissima*, Sladen.
**Hymenaster*[4] *cælatus*, Sladen.
* „ *coccinatus*, Sladen

of its calyx, for it is the only Comatula yet found at a greater depth than 2000 fathoms. *Bathycrinus*, and perhaps also *Hyocrinus*, extend down to 2400 fathoms; *Promachocrinus* and *Thaumatocrinus* occur at 1800 fathoms, but with the exception of *Antedon abyssicola*, no other Comatulæ have been found below 1600 fathoms, at which depth (Station 147) *Antedon abyssorum*, *Antedon bispinosa*, and *Antedon remota* were obtained. *Antedon abyssicola* has been dredged, however, at two Stations, one (Station 160) shortly before the Challenger reached Melbourne, where the depth was 2600 fathoms, and the other in the deepest part of the North Pacific at 2900 fathoms (Station 244). *Antedon abyssicola* thus resembles *Antedon alternata* in occurring at widely separated localities in the abyssal region, and it has some points of resemblance with the younger individuals of this type.—(CARPENTER, *Zool. Chall. Exp.*, part 60, pp. 191–2.)

[1] *Antedon bispinosa* has such very definite characters that it is not likely to be confounded with any other. The spiny calyx and the double row of long hook-like spines along the arms distinguish it very clearly. . . . It is rather a robust species for such a considerable depth (1600 fathoms). But the sacculi are poorly developed, as is so often the case in the abyssal Comatulæ.—(CARPENTER, *Zool. Chall. Exp.*, part 60, p. 116.)

[2] *Bathycrinus* ranges through a greater number of degrees of latitude than any other stalked Crinoid, even *Rhizocrinus;* and it is only surpassed in this respect by the ubiquitous *Antedon*. *Bathycrinus carpenteri* was found by the Norwegian North Sea Expedition as far north as 65° 55′ N. lat.; while *Bathycrinus aldrichianus* was twice met with by the Challenger in the Southern Ocean beyond the parallel of 46° S. lat. In the intervening Atlantic Ocean have been found *Bathycrinus gracilis* (Bay of Biscay) and *Bathycrinus campbellianus* (just north of the equator); while other examples of the genus were dredged by the "Talisman" in the Atlantic at a depth of from 2000 to 2380 metres (1200 fathoms). It is distinctly an abyssal type, ranging from 1050 to 2435 fathoms. The only Crinoids which have been found at greater depths than the latter are two species of *Antedon*.—(CARPENTER, *Zool. Chall. Exp.*, part 32, p. 237.)

[3] As now classified the species [of the genus *Freyella*] present a remarkable similarity of general facies, and the comparatively small amount of morphological plasticity exhibited by the genus is extraordinary, considering the wide geographical area over which it is distributed. The bathymetrical range is also remarkable, extending from the commencement of the continental zone to the greatest depth at which starfishes have been found.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 615.)

[4] The dredgings of the Challenger Expedition have now shown that *Hymenaster* possesses a world-wide distribution in deep waters, and that the genus exhibits a remarkable amount of morphological plasticity, no less than twenty-four species being now known. The bathymetrical range of the genus is also remarkable, as, with the exception of the type form (*Hymenaster pellucidus*), which ranges from 70 to 1539 fathoms, all the species are confined to the abyssal zone. One, *Hymenaster infernalis*, extends to 2900 fathoms, the greatest depth at which starfishes have hitherto been found; and four other species occur in depths greater than 2000 fathoms. . . . The general facies of the type appears to be one of great antiquity. This, however, is not the place to discuss, as I should desire, the archaic relationships of existing Asterids; and I would therefore now only briefly direct attention to the remarkable resemblance and, in many respects, apparent similarity of general character, which exist between *Hymenaster* and the recently described *Loriolaster* of STÜRTZ from the Lower Devonian slates of Bundenbach.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 492.)

**Hymenaster crucifer*, Sladen.
* ,, *formosus*, Sladen.
* ,, *graniferus*, Sladen.
* ,, *latebrosus*, Sladen.
,, *nobilis*, Wyville Thomson.
* ,, *præcoquis*, Sladen.
* ,, *sacculatus*, Sladen.
**Hyphalaster planus*, Sladen.
**Lonchotaster forcipifer*, Sladen.
**Pararchaster antarcticus*, Sladen.
,, *pedicifer*, Sladen.
Pontaster forcipatus, Sladen, var. *echinata*, Sladen.
Porania antarctica,[1] Smith.

OPHIUROIDEA :

**Amphiura patula*, Lyman.
Ophiacantha cosmica, Lyman.
Ophiernus vallincola, Lyman.
Ophiocten amitinum, Lyman.
,, *hastatum*, Lyman.
* ,, *pallidum*, Lyman.
**Ophiocymbium cavernosum*, Lyman.
**Ophioglypha fraterna*, Lyman.
,, *lacazei*, Lyman.
* ,, *lienosa*, Lyman.
* ,, *loveni*, Lyman.
* ,, *minuta*, Lyman.
Ophiolebes scorteus, Lyman.
**Ophiomitra sarsii*, Lyman.
**Ophioplinthus grisea*, Lyman.
* ,, *medusa*, Lyman.

ECHINOIDEA :

Cystechinus vesica, Agassiz.
,, *wyvillii*, Agassiz.
**Echinocrepis cuneata*, Agassiz.
Echinus magellanicus, Philippi.
**Genicopatagus affinis*, Agassiz.
Goniocidaris canaliculata, Agassiz.

[1] This species [*Porania antarctica*] may be distinguished from the rather closely related northern *P. pulvillus*, Müller, by differences in the ambulacral spines, and in the number and character of the marginal spines.—(E. A. SMITH, *Phil. Trans.*, vol. 168, p. 276.)

Pourtalesia[1] *carinata*, Agassiz.
,, *ceratopyga*, Agassiz.
* ,, *hispida*, Agassiz.
,, *phiale*, Wyville Thomson.
Schizaster[2] *moseleyi*, Agassiz.
**Spatagocystis challengeri*, Agassiz.
Urechinus naresianus, Agassiz.

HOLOTHURIOIDEA:

**Achlyonice lactea*, Théel.
Benthodytes sanguinolenta, Théel, var. *marginata*, Théel.
,, *sordida*, Théel.
Cucumaria abyssorum, Théel.
,, ,, var. *hyalina*, Théel.
**Elpidia ambigua*, Théel.
,, *glacialis*, Théel.
* ,, *incerta*, Théel.
* ,, *purpurea*, Théel.
* ,, *willemoesi*, Théel.
Holothuria thomsoni,[3] Théel, var. *hyalina*, Théel.
Kolga nana, Théel.
Lætmogone wyville-thomsoni, Théel.
Oneirophanta mutabilis, Théel.
**Peniagone affinis*, Théel.
* ,, *atrox*, Théel.
* ,, *challengeri*, Théel.

[1] In the genus *Pourtalesia* proper, as I have retained it here, there are two groups of species readily distinguished from the character of the test; these I was at first inclined to separate into distinct sub-genera on comparing such extreme forms as *Pourtalesia miranda*, *laguncula*, and *phiale* with such forms as *Pourtalesia ceratopyga* and *rosea*. The former group is distinguished by the extreme tenuity, almost transparency, of the test and its more or less bottle-shaped outline, while the latter group contains species with a flattened test, a triangular outline from above, and a comparatively thickened test.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 132–3.)

[2] The limits which have been assigned to the genera closely allied to *Schizaster* are very unsatisfactory, and the generic characters by which different species are assigned to these genera or sub-genera pass so gradually one into the other, not merely among the recent species, but especially when we come to include the fossil species, that the task of properly limiting them appears hopeless, although these characters are convenient as sub-divisions according to which we may associate groups of species.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, p. 200.)

[3] The three species above mentioned, viz., *Holothuria lactea*, *Holothuria thomsoni*, and *Holothuria murrayi*, form a group by themselves among the numerous representatives of the genus *Holothuria*, and it is very probable that they may be properly placed in a new genus, or, at least, in a sub-genus. Indeed, *Holothuria thomsoni* differs so strikingly from all forms hitherto known that I should not hesitate to refer it to a new genus if I had not had the opportunity of examining the two other forms, which evidently form a transition to the true *Holothuriæ*. *Holothuria thomsoni* is distinguished by twelve tentacles, and its variety by fifteen, numbers of tentacles hitherto unknown in any species of *Holothuria*. That which seems to be common to the three species above mentioned and their varieties is, firstly, the conformation of the calcareous deposits, and secondly, the peculiarity that the pedicels of the two lateral ventral ambulacra either form a simple distinct row, or that, if they are more numerous and crowded, some of them are larger and more or less distinctly arranged in a row along each side of the body.—(THÉEL, *Zool. Chall. Exp.*, part 38, p. 187.)

**Peniagone horrifer*, Théel.
* „ *naresi*, Théel.
Pseudostichopus villosus, Théel.
„ „ var. *violaceus*, Théel.
Psychropotes longicauda, Théel.
* „ „ var. *fusco-purpurea*, Théel.
* „ „ var. *monstrosa*, Théel.
* „ *loveni*, Théel.
**Scotoanassa diaphana*, Théel.
Scotoplanes globosa, Théel.
* „ *insignis*, Théel.
* „ *mollis*, Théel.
* „ *murrayi*, Théel.
* „ *robusta*, Théel.

ENTOZOA :

**Ascaris macruroidei*, Linstow.
**Prothelmins profundissima*, Linstow.

NEMERTEA :

Pelagonemertes rollestoni, Moseley.

GEPHYREA :

**Phascolion lutense*, Selenka.

ANNELIDA :

**Amphicteis wyvillei*, M'Intosh.
**Ephesia antarctica*, M'Intosh.
**Eunoa abyssorum*, M'Intosh.
**Grubianella antarctica*, M'Intosh.
Hyalinœcia benthaliana, M'Intosh.
Lætmonice producta, Grube, var. *benthaliana*, M'Intosh.
„ „ var. *willemoesi*, M'Intosh.
„ „ var. *wyvillei*, M'Intosh.
**Lagisca crosetensis*, M'Intosh.
**Leæna antarctica*, M'Intosh.
**Maldanella antarctica*, M'Intosh.
Nothria abranchiata (= *abyssicola*), M'Intosh.
* „ *armandi*, M'Intosh.
**Petta assimilis*, M'Intosh.
**Pista abyssicola*, M'Intosh.
**Polynoë ascidioides*, M'Intosh.

Polynoë (Admetella) longipedata, M'Intosh.
Praxilla abyssorum, M'Intosh.
Trophonia wyvillei, M'Intosh.

MYZOSTOMIDA :

Myzostoma compressum, Graff.
* „ *coronatum*, Graff.
Stelechopus hyocrini, Graff.

OSTRACODA :

Bairdia[1] *bosquetiana*, Brady.
Cythere[2] *acanthoderma*, Brady.
„ *dasyderma*, Brady.
„ *dictyon*, Brady.
* „ *viminea*, Brady.
Cytheropteron abyssorum, Brady.
„ *mucronalatum*, Brady.
Krithe producta,[3] Brady.
Macrocypris similis, Brady.

CIRRIPEDIA :

Scalpellum[4] *antarcticum*, Hoek.
* „ *brevicarinatum*, Hoek.
* „ *flavum*, Hoek.
* „ *improvisum*, Hoek, MS.
* „ *planum*, Hoek.
* „ *tenue*, Hoek.

[1] *Bairdia* is a widely dispersed genus, attaining, apparently, its greatest development in the tropical and southern seas, in dredgings from which regions the number of specimens of *Bairdiæ* not unfrequently exceeds that of all other Ostracoda together ; the individuals, however, though numerous, are usually found to belong in each gathering to one, or at most two, predominant species.—(G. S. BRADY, *Zool. Chall. Exp.*, part 4, p. 48.)

[2] The genus *Cythere* includes probably nearly as many species, recent and fossil, as all the remaining genera [of Ostracoda] put together, the number assigned to it in this monograph being 83 out of a total of 221. But though in its present form excessively unwieldy, it seems impossible, without a more perfect knowledge than we yet possess of the variations of anatomical structure in the several species, either to form useful sub-genera, or to separate from the main group any true generic types.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 62.)

[3] This species [*Krithe producta*] is either a cosmopolitan one, and very variable as to shape, or the figures given under its name, which are fairly representative of many different examples, must belong to other undescribed species. I prefer, however, to consider them as forms of *Krithe producta*, the variations observable in a large series of specimens being almost countless, and, as I think, in many cases fairly referable to differences of age, sex, or race.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 114.)

[4] *Scalpellum* seems to be the only genus of Cirripedia which is often met with in the great depths of the ocean. This strikingly coincides with the common occurrence of this genus in the fossil deposits, especially in secondary strata (Cretaceous period). . . . The great number of species in this genus suggested the idea of dividing it into smaller genera. After careful examination this idea, however, has been given up, as all the species in essential characters correspond as closely, even more closely, with one another than in any other genus of Cirripedia. Nor has it been an easy matter to arrange the species in a natural way.—(HOEK, *Zool. Chall. Exp.*, part 25, p. 60.)

AMPHIPODA :

**Andania gigantea*, Stebbing.
**Lanceola*[1] *australis*, Stebbing.
Phronima[2] *novæ-zealandiæ*, Powell.
**Pleustes abyssorum*, Stebbing.
**Valettia coheres*, Stebbing.

ISOPODA :

**Acanthocope spinicauda*, Beddard.
**Arcturus brunneus*, Beddard.
,, *furcatus*, Studer.
* ,, *glacialis*, Beddard.
* ,, *spinosus*, Beddard.
Eurycope fragilis, Beddard.
* ,, *sarsii*, Beddard.
* ,, *spinosa*, Beddard.
,, sp. (?).
**Iolanthe acanthonotus*, Beddard.
**Ischnosoma bacillus*, Beddard.
**Munnopsis australis*, Beddard.
Serolis antarctica, Beddard.
,, *bromleyana*, Suhm.

PHYLLOCARIDA :

Nebaliopsis typica, Sars.

SCHIZOPODA :

**Amblyops crozetii*, Suhm (MS.), Sars.
Bentheuphausia amblyops, Sars.
Boreomysis scyphops, Sars.

[1] From west to east the genus *Lanceola* may be considered as ranging round the world, while from north to south a range is shown of more than ninety degrees, to which may be added about thirty degrees northward, since *Lanceola clausii* was taken in Davis Strait, lat. 72° N. It is remarkable that each of the Challenger specimens was labelled, not, like most of the Hyperina with the word "surface," but with the number of fathoms of the particular station, indicating that the specimen was supposed to have come from the great depth mentioned. It may be conjectured that the smallness of the eyes and the soft membranaceous character of the integument are connected with residence in the abysses of the ocean, and the latter character perhaps also with a capacity for passing without injury from the bottom to the surface. The pleopods are well developed, so that the animal may be itself a good swimmer, but, to account for the wide distribution of the genus, it may be supposed that the creature often avails itself of extraneous assistance, the retractile claws of the last three pairs of peræopods being well adapted for giving it a firm hold upon animals of much greater size and speed.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 1317.)

[2] The range of the genus *Phronima* as illustrated by the Challenger specimens is between lat. 36° 23′ N. and 50° 1′ S., and over a space of 223 degrees between long. 13° 5′ W. and 123° 4′ E. Specimens from the Shetland Isles carry the range in latitude up to 60° N. in the Atlantic ; Dr STREETS extends it to 40° N. in the Pacific ; and since Dr GILES has added the Bay of Bengal to so many other localities from which the genus is known, its range from east to west may fairly be considered as extending all round the world.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 1361.)

**Chalaraspis alata*, Suhm.
Eucopia australis,[1] Dana.
Gnathophausia[2] *gigas*,[3] Suhm.
Pseudomma[4] *sarsii*, Suhm.

MACRURA :

**Glyphocrangon*[5] *podager*, Bate.
**Hymenodora*[6] *duplex*, Bate.
„ *mollicutis*, Bate.
**Nematocarcinus*[7] *lanceopes*, Bate.
„ *proximatus*, Bate.
**Petalidium foliaceum*, Bate.

[1] This Schizopod [*Eucopia australis*] would appear, on the whole, to be a true deep-sea form, ranging, as it does, from a depth of 1000 to 1975 fathoms. It is worthy of remark, however, that the specimen described by DANA was taken from the stomach of a penguin; and, as it cannot be reasonably assumed that any air-breathing animal can descend to the enormous depths stated above, the said form may also be considered as occasionally occurring at a less considerable depth. It would seem, too, that this view is in part corroborated by the statement of the late Dr v. WILLEMOES-SUHM, who says that in the Atlantic this species is met with at depths ranging from 350 to 2500 fathoms. The late Dr v. WILLEMOES-SUHM observes concerning this form that "it is the commonest Schizopod of the deep-sea fauna, and seems to enjoy a very wide bathymetrical and geographical distribution." Indeed its geographical range is quite astounding, for it is met with not only throughout the great depths of the Atlantic, but also in the Antarctic Ocean, the Australian seas, and even in the Pacific, as far north as Japan.—(SARS, *Zool. Chall. Exp.*, part 37, p. 62.)

[2] All the species belonging to the genus *Gnathophausia* seem to be well-marked deep-sea forms. The least depth from which specimens have been obtained is 250 fathoms, and the greatest 2200 fathoms. *Gnathophausia* has never been taken at the surface of the sea; it may therefore certainly be assumed that these Crustacea, notwithstanding their strongly developed natatory organs, never leave the deeper strata of the sea, and that in all probability they have their habitat on the sea-bottom itself. . . . The genus seems to exhibit a very extensive geographical distribution, being most probably represented throughout the greater part of the ocean, excepting perhaps the Arctic and Antarctic regions. Thus, species of this genus have been recorded both from the North and South Atlantic, from the Pacific, and from the seas of the Indian Archipelago. The genus may even be reckoned among the European fauna, one of its species having been found by the French expedition in the Bay of Biscay.—(SARS, *Zool. Chall. Exp.*, part 37, p. 29.)

[3] Exclusive of the specimen of *Gnathophausia gigas* taken in the North Atlantic, west of the Azores, I also found among the material placed in my hands for examination the recently moulted skin of the outer part of the tail of another specimen, apparently belonging to the same species, brought up in the Southern Ocean, between Kerguelen and Australia. Hence the species seems to exhibit a rather extensive geographical distribution, its occurrence in both hemispheres having been ascertained.—(SARS, *Zool. Chall. Exp.*, part 37, p. 35.)

[4] Of this genus [*Pseudomma*] three northern species have been recorded; two additional species were met with on the Challenger Expedition, both in the southern hemisphere.—(SARS, *Zool. Chall. Exp.*, part 37, pp. 188–9.)

[5] The various forms of this genus [*Glyphocrangon*] can scarcely be considered as being more than varieties of one great type; the specific differences being little else than a greater or less exaggeration of features common to them all. —(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 507.)

[6] The species of this genus [*Hymenodora*], like most of the family, are from deep water; only two specimens of one species being taken at a less depth than 2 miles. They are mostly found in mid ocean, on a bottom of mud or ooze: in the Atlantic beneath the equator and as far south as Tristan, and in the Indian Ocean as far south as Kerguelen. BUCHHOLZ's specimen was taken at the surface near the pack ice in lat. 78° N. . . . In the most typical forms the eyes have almost entirely lost their pigment; in some species it is reduced to a brown colour, and in a few it is black, as if the degree of pigmentation was dependent upon variation in depth and degree of light.—(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 841.)

[7] I am inclined to believe that the animals [of the genus *Nematocarcinus*] live at an average depth of between 300 and 500 fathoms in mid-water.—(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 801.)

ANOMURA:

Munidopsis[1] *antonii* (M.-Edwards, MS.).
,, *subsquamosa*, Henderson, var. *aculeata*, Henderson.
Pagurodes inarmatus, Henderson.

PYCNOGONIDA:

**Ascorhynchus glaber*, Hoek.
Colossendeis gigas, Hoek.
* ,, *gigas-leptorhynchus*, Hoek.
* ,, *gracilis*,[2] Hoek.
,, *leptorhynchus*, Hoek.
**Nymphon hamatum*, Hoek.
* ,, *meridionale*, Hoek.
**Phoxichilidium pilosum*, Hoek.

LAMELLIBRANCHIATA:

Amussium meridionale, Smith.
Kellia (?) sp.
Leda sp. (?).
Lima (*Limatula*) sp. (?).
,, (?) sp.
**Lyonsiella papyracea*, Smith.
**Neæra* [= *Cuspidaria*] *meridionalis*, Smith.
**Pecten pudicus*, Smith.
Silenia sarsii, Smith.

SCAPHOPODA AND GASTEROPODA:

**Dentalium leptoskeles*, Watson.
**Fusus* (*Neptunea*) *calathiscus*, Watson.
* ,, (,,) *setosus*, Watson.
**Guivillea alabastrina*, Watson.
Lamellaria sp. (?).
Pleurobranchus sp. (?).
**Pleurotoma* (*Pleurotomella*) *papyracea*, Watson.

[1] The members of this genus [*Munidopsis*] have been taken in almost all seas the deep water of which has been explored by the dredge, and they are found at depths varying from about 100 to upwards of 2000 fathoms. The species differ widely among themselves in the form of those parts which in other Crustacea afford generic characters; and yet it is impossible to effect a natural sub-division, or one which is not founded on a single character to the exclusion of others. It is probable that the loss of sight is compensated by a greater development of the tactile sense, and in some species this is evidenced by the great length of the antennal flagella, which in all probability enable the animal to grope its way about on the bottom.—(HENDERSON, *Zool. Chall. Exp.*, part 69, p. 148.)

[2] Whether I am right or not in considering the specimens collected at Stations 146 and 147 (*Colossendeis gracilis*), Station 298 (*Colossendeis media*), and Station 325 (*Colossendeis brevipes*), as three different species can only be ascertained by examining a larger number of specimens than are at my disposal. I can only point out here the great affinity of these different specimens.—(HOEK, *Zool. Chall. Exp.*, part 10, p. 73.)

Peurotoma (Surcula) lepta, Watson.
„ („) *staminea*, Watson.
Trochus (Margarita) brychius, Watson.
„ („) *infundibulum*, Watson.

CEPHALOPODA :

Bathyteuthis abyssicola,[1] Hoyle.
Cirroteuthis magna, Hoyle.
Eledone rotunda, Hoyle.

POLYZOA :

Bicellaria infundibulata, Busk.
Bugula[2] *bicornis*, Busk.
„ *reticulata*, Busk.
Cellepora[3] *solida*, Busk.
Farciminaria[4] *magna*, Busk.
Foveolaria orbicularis, Busk.
Idmonea marionensis, Busk.
Onchopora sinclairii, Busk.
Salicornaria magnifica, Busk.

BRACHIOPODA :

Terebratula wyvillii,[5] Davidson.

[1] Notwithstanding the great distance between the localities where this species [*Bathyteuthis abyssicola*] and VERRILL'S *Bentheoteuthis megalops* [North Atlantic] were captured, it seems quite possible that they may ultimately prove to be the same species (HOYLE, *Zool. Chall. Exp.*, part 44, p. 169).

[2] In order to include several of the species in the present collection, and to avoid the creation of one or more new genera, I have thought it better in this catalogue so to modify the definition of *Bugula* as to admit of these, for the most part, new forms being placed in it. . . . The group, however, as thus made up, includes several apparently distinct types, which will probably at some time be thought of at least sub-generic value. . . . It may also be observed that the first and second of these groups consist almost exclusively of very deep-water forms, the shallowest being 150 fathoms, whilst the depths from which the other species, included in those groups, were brought up was on the average not less than 2000 fathoms. They would appear therefore to constitute a distinctively abyssal type. . . . The group affords a striking instance of the comparatively large size and free growth, and at the same time of the extremely delicate structure, characteristic it may almost be said of the Polyzoa that live in the tranquil depths of the ocean.—(BUSK, *Zool. Chall. Exp.*, part 30, pp. 37, 38.)

[3] The species of this multiform and perplexing genus [*Cellepora*] may be conveniently arranged in two principal more or less artificial sections or groups, characterised primarily by the form of the operculum and secondarily by the general zoarial habit. . . . On the whole the genus would appear to belong to comparatively shallow water.—(BUSK, *Zool. Chall. Exp.*, part 30, pp. 191–2.)

[4] The genus *Farciminaria* may be regarded emphatically as abyssal; the mean depth at which the species here enumerated occurred being not less than 1500 to 1600 fathoms, or from 450 to 2750 fathoms.—(BUSK, *Zool. Chall. Exp.*, part 30, p. 49.)

[5] *Terebratula wyvillii* is one of the most interesting species of deep-sea Brachiopoda dredged during the Challenger Expedition. It appears to abound over a wide geographical range, and at depths varying from 1035 to 2900 fathoms. The shell is of such extreme thinness that it is almost transparent; indeed, the valves when separated are really so, and the muscular impressions may be seen through its transparency. It is also exceedingly brittle. It bears much resemblance to several species occurring in the Jurassic and Cretaceous formations and especially so to *Terebratula boneti*, Zeuschner, from the Kimmeridge of Switzerland, and from which some of the Challenger specimens are scarcely distinguishable, either by size or shape.—(DAVIDSON, *Zool. Chall. Exp.*, part 1, pp. 27, 28.)

TUNICATA :

**Abyssascidia vasculosa*, Herdman.
* ,, *wyvillii*, Herdman.
**Bathyoncus mirabilis*, Herdman.
Corynascidia suhmi, Herdman.
**Culeolus*[1] *perlucidus*, Herdman.
,, *recumbens*, Herdman.
**Fungulus cinereus*, Herdman.
**Pharyngodictyon mirabile*, Herdman.
**Styela bythia*, Herdman.
* ,, *sericata*, Herdman.
* ,, *squamosa*, Herdman.

FISHES :

Antimora rostrata, Günther.
**Bathydraco antarcticus*,[2] Günther.
**Bathylagus*[3] *antarcticus*, Günther.
Cyema atrum,[4] Günther.
Gonostoma microdon, Günther.
Halosaurus[5] *macrochir*, Günther.
Macrurus[6] *armatus*,[7] Hector.

[1] The genus *Culeolus* has a very considerable horizontal range, two of the species being found in the northern hemisphere, while the remaining four are from the southern. Those in the northern seas are from the temperate zone, while of the southern forms, one is from near the equator, one from between 20° to 30° S. lat., and the remaining two species are from much further south. . . . *Culeolus* is a peculiarly deep-water genus, but has a considerable range, viz., from 630 to 2425 fathoms. Five of the species are from upwards of 1000 fathoms, four from over 1500 fathoms, and two from upwards of 2000 fathoms. Thus they all belong to the abyssal fauna.—(HERDMAN, *Zool. Chall. Exp.*, part 17, pp. 265, 270.)

[2] *Bathydraco antarcticus* is clearly allied to *Chœnichthys;* its habitat at a great depth is evidenced by the diminished proportion of earthy matter in the bones of the skull, by its large eyes, wide muciferous channels, and coloration.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 48.)

[3] In *Bathylagus* the thinness of the bones, the fragility of the fin-rays, the delicacy of the skin and scales, and the enormously large eyes, seem to be sufficient evidence that these fishes are actually inhabitants of very great depths. These fishes must therefore be entirely dependent for vision on the phosphorescent light which is produced by other abyssal creatures. Not being fish of prey themselves, or only to a slight degree, they would be attracted by the light issuing from the Pediculates and Stomiatids of the deep, and thus fall an easy prey to these fishes.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 219.)

[4] *Cyema atrum* is extremely interesting, inasmuch as it is still nearer to the Leptocephalid condition than *Nemichthys infans*. In fact, I had to consider the possibility of its being a less advanced stage of development of that species; however, the minute size of the eye disposes of the idea of genetic affinity.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 266.)

[5] Of the genus *Halosaurus* which hitherto was known from a single example only, four species were discovered by the Challenger, showing that it is widely and abundantly represented in the deep sea.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 232.)

[6] Before the Challenger Expedition the known species of *Macrurus* were few in number . . . The drédge of the Challenger secured more than 140 examples referable to thirty species, and proved that this type of fishes is not only one of the most widely spread in the depths of all oceans, but also extremely abundant with regard to species and individuals.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 122.)

[7] *Macrurus armatus* has a wide range in the southern hemisphere, and is subject to some variation, the variation

Macrurus filicauda,[1] Günther.
Melamphaës[2] *crassiceps*, Günther.
* „ *microps*, Günther.
**Melanonus gracilis*, Günther.
**Scopelus*[3] *antarcticus*, Günther.
Stomias boa (Risso).
Synaphobranchus bathybius, Günther.

The 272 species enumerated in the above list include one or two species of Medusæ, Siphonophoræ, Amphipoda, and Fishes undoubtedly belonging to the surface and intermediate water fauna; these might have been eliminated, but it has been considered best to allow them to remain as they occur in the Challenger lists. With these exceptions, however, all the above species live on or near the bottom beyond 1000 fathoms.

The great majority of the species were each taken only at one of the eight Stations, but a few occurred at more than one of these Stations.

LIST I *a*.

It may be of interest to give here a list of such species, indicating in brackets the number of Stations at which each species was found. It will be noticed that out of the 57 species occurring at more than one Station, not a single one occurred at all the Stations, nor even at seven out of the eight Stations, while only 1 species occurred at six Stations, 1 at five Stations, 2 species each at four Stations, 13 species each at three Stations, and the remaining 40 species each at two Stations. This does not seem to

occurring in individuals from the same locality, and affecting the form of the head, length of dorsal spine, &c. The most striking deviation from the typical form is a kind of albino, not quite white, but of a much lighter colour than the ordinary specimens. In these albinos the scales are much thinner, the ridges sometimes scarcely visible, and if developed, they are merely keels without spines.—(Günther, *Zool. Chall. Exp.*, part 57, p. 150.)

[1] This species [*Macrurus filicauda*] is clearly one of those in this family which extend to the greatest depths. The decrease in the size of the eye, the very soft bones, the concomitant want of firmness in the structure of the scales, and the tail, which tapers into a very fine filament, indicate its abyssal abode. The scales are nearly all gone in all the specimens obtained. This species appears to be abundant in individuals, and has, like a true deep-sea fish, a wide distribution.—(Günther, *Zool. Chall. Exp.*, part 57, p. 142.)

[2] The formation of the head, the black colour of the body, together with the circumstances attending the capture of the three specimens first known, clearly indicate that the fishes of this genus [*Melamphaës*] are inhabitants of the depths of the ocean. Lowe's two specimens were picked up at the surface, near Madeira, evidently in an exhausted condition; whilst the specimen described by Lütken was found in the stomach of a dolphin. The discoveries by the Challenger, and by the U.S.S. "Albatross," have proved the surmise of the bathybial nature of these fishes to be correct.—(Günther, *Zool. Chall. Exp.*, part 57, p. 26.)

[3] The numerous species which I refer to this genus [*Scopelus*] are, as far as we know of their habits, nocturnal pelagic surface fishes, which are frequently caught at night in the surface net, but disappear during the daytime, when they evidently descend to a depth to which only a moderate amount of light penetrates. A few undoubtedly belong to the bathybial fauna, but with regard to the other species, I consider it equally probable that they accidentally entered the dredge during its ascent. Only a few specimens were captured in this manner, much fewer than of *Argyropelecus*, a fact which is no doubt due to their greater activity, by which they are enabled to make their escape on perceiving the approach of the net.—(Günther, *Zool. Chall. Exp.*, part 57, pp. 195–6.)

indicate that many of the deep-sea species have a wide distribution. The probability is that further trawlings and dredgings will yield a very large number of new species and genera.

Holascus fibulatus (3).
Umbellula carpenteri (2).
„ *magniflora* (2).
Bathyactis symmetrica (2).
Leptopenus discus (2).
Bathycrinus aldrichianus[1] (2).
Promachocrinus abyssorum (2).
Brisinga membranacea (2).
Freyella fragilissima (2).
Hymenaster præcoquis (2).
Lonchotaster forcipifer (2).
Ophiacantha cosmica (6).
Ophiernus vallincola (2).
Ophiocten amitinum (3).
„ *pallidum* (2).
Ophioglypha loveni (5).
„ *minuta* (2).
Cystechinus wyvillii (3).
Goniocidaris canaliculata (3).
Pourtalesia carinata (2).
„ *hispida* (2).
Spatagocystis challengeri (2).
Urechinus naresianus (3).
Benthodytes sanguinolenta (2).
„ *sordida* (3).
Cucumaria abyssorum (2).
Elpidia purpurea (2).
Lætmogone wyville-thomsoni (2).
Oneirophanta mutabilis (3).
Pseudostichopus villosus (4).
Psychropotes longicauda (2).
Phascolion lutense (2).
Grubianella antarctica (3).
Lætmonice producta (3).
Maldanella antarctica (3).
Scalpellum brevicarinatum (2).
Andania gigantea (2).
Eurycope fragilis (3).
„ *sarsii* (2).
Serolis antarctica (2).
Boreomysis scyphops (3).
Eucopia australis (2).
Hymenodora mollicutis (2).
Petalidium foliaceum (2).
Colossendeis gigas (2).
„ *gracilis* (2).
„ *leptorhynchus* (2).
Nymphon hamatum (2).
Phoxichilidium pilosum (2).
Amussium meridionale (2).
Dentalium leptoskeles (2).
Fusus (*Neptunea*) *setosus* (2).
Bicellaria infundibulata (2).
Gonostoma microdon (2).
Macrurus armatus (4).
„ *filicauda* (3).
Scopelus antarcticus (2).

The preceding list of species from the deep-water area of the Kerguelen Region (List I.) shows that in the region of the Southern Indian Ocean represented by the eight Stations referred to, the Challenger procured in depths exceeding 1260 fathoms representatives of 272 species and varieties of Metazoa, belonging to 186 genera. The large proportion of genera relatively to the number of species is striking, being as 1 to 1·46.

An examination of the list shows that 9 of the species have received no specific names, owing to the specimens being in an unsatisfactory condition or to other causes, and they cannot therefore be taken into account in any discussion of distribution. There are besides 6 varieties enumerated, as well as the species to which they belong, but in what follows the distribution of each species is considered as a whole, including varieties. Of 2 species (*Stephanoscyphus simplex* and *Bairdia bosquetiana*) we have no trustworthy information as to distribution, so that we must deduct from the total number of species

[1] Wyville Thomson says this species was taken at, at least, six or seven Stations in the Atlantic and Southern Sea, but it is recorded in the Challenger Report only from two of these Stations.

(272), 9 unnamed species, 6 varieties, and 2 species of which we have no information, leaving 255 distinct fully-described species, the distribution of which may be discussed in detail.

These 255 species naturally fall into two divisions, viz., those that are known only from the region represented by these eight Stations, and those that are known from other regions of the ocean.

a. *Species limited to the area under consideration.*

In the first place, we find that there are 164 species (or 60 per cent. of the total number of species and varieties found at these eight Stations) which, as far as we know up to the present time, are limited to the region represented by these eight Stations. These 164 species are distinguished by an asterisk in the list, and very little can be said about them beyond the fact that they are known only from this area and from depths over 1260 fathoms.

LIST I *b*.

We may here, however, enumerate those species found at more than one of these Stations, indicating in brackets the number of Stations at which each species was found. It will be observed that here again the species limited to this area do not show a wide distribution within the area itself, for out of the 28 species occurring at more than one Station, 24 species were each taken at two Stations, 3 species were each taken at three Stations, and 1 species was taken at five Stations.

Holascus fibulatus (3).
Umbellula carpenteri (2).
„ *magniflora* (2).
Promachocrinus abyssorum (2).
Brisinga membranacea (2).
Freyella fragilissima (2).
Hymenaster præcoquis (2).
Lonchotaster forcipifer (2).
Ophiocten pallidum (2).
Ophioglypha loveni (5).
„ *minuta* (2).
Pourtalesia hispida (2).
Spatagocystis challengeri (2).
Elpidia purpurea (2).
Phascolion lutense (2).
Grubianella antarctica (3).
Maldanella antarctica (3).
Scalpellum brevicarinatum (2).
Andania gigantea (2).
Eurycope sarsii (2).
Petalidium foliaceum (2).
Colossendeis gracilis (2).
Nymphon hamatum (2).
Phoxichilidium pilosum (2).
Dentalium leptoskeles (2).
Fusus (Neptunea) setosus (2).
Bicellaria infundibulata (2).
Scopelus antarcticus (2).

b. *Species extending outside the area under consideration.*

We come now to consider those species which have a wider distribution and extend into other regions of the ocean outside the area represented by these eight Stations. The number of such species is 91 (or 33 per cent. of the total number of species and varieties

found at these eight Stations), and for the purpose of considering their geographical distribution they may most conveniently be divided into groups according as they have been recorded from the tropical and extra-tropical regions of the ocean. Thus we find that of these 91 species,

38 species (or 42 per cent.) are known, up to the present time, to occur in regions south of the southern tropic outside the area under consideration (List I*c.*);

24 species (or 26 per cent.) are known to occur in regions both south and north of the tropics, but not in the intervening tropical zone (List I*d.*);

12 species (or 13 per cent.) are known to occur in regions both south of and between the tropics, but not north of the tropical zone (List I*e.*); and

17 species (or 19 per cent.) are known to occur in regions both south of, between, and north of the tropics, and some of them may for the present be regarded as almost cosmopolitan or very widely distributed in the deep sea (List I*f.*).

We may now proceed to consider in detail the distribution of these 91 species, according to the groups given above, indicating briefly the geographical and bathymetrical distribution of each species outside the region represented by these eight Stations.

LIST I *c.*

In the first place, we give a list of the 38 species which are known to occur outside the region under consideration in somewhat similar latitudes, *i.e.* in regions south of the tropic of Capricorn, but not in other regions of the deep sea. From the distributional notes accompanying each species it will be observed that 26 of the species are eminently deep-sea species, being unknown from depths less than 1000 fathoms; the other 12 species, though found in depths greater than 1000 fathoms in the region represented by these eight Stations, occur outside this region in depths less than 1000 fathoms, and 8 of these species are recorded from shallow water under 150 fathoms.

Leptopenus discus—Western South Atlantic, 1900 fathoms.
Pararchaster pedicifer—South Atlantic, 1900 fathoms (doubtfully referred to the young of this species).
Porania antarctica—Near Marion Island, 50 to 150 fathoms; Kerguelen and South Georgia.
Ophiocten amitinum—Near Marion and Kerguelen Islands, 85 to 150 fathoms.
Ophioglypha lacazei—Eastern South Pacific, 2160 fathoms.
Ophiolebes scorteus—Near Marion Island, 310 fathoms.
Cystechinus vesica—Eastern South Pacific, 2160 and 2225 fathoms.
„ *wyvillii*—Eastern South Pacific, 1375 to 2160 fathoms.
Echinus magellanicus—Near Marion Island, Falklands, and Magellan Strait, 9 to 310 fathoms: Chili, Cape, Australia, New Zealand.
Pourtalesia carinata—Eastern South Pacific, 2225 fathoms.
„ *ceratopyga*—Eastern South Pacific, 2160 and 2225 fathoms.
Schizaster moseleyi—Near Kerguelen and Magellan Strait, 40 to 400 fathoms.

Urechinus naresianus—Eastern South Pacific, 1450 fathoms.
Benthodytes sanguinolenta—Eastern South Pacific, 2225 fathoms.
„ *sordida*—Eastern South Pacific, 2225 fathoms.
Cucumaria abyssorum—Eastern South Pacific, 1375 to 2225 fathoms.
Psychropotes longicauda—Eastern South Pacific, 2225 fathoms.
Scotoplanes globosa—Eastern South Pacific, 2160 fathoms.
Hyalinœcia benthaliana—South Pacific near New Zealand, 1100 fathoms.
Nothria abranchiata—Mid South Atlantic, 1425 fathoms.
Arcturus furcatus—Near Kerguelen and Heard Islands, 7 to 127 fathoms.
Serolis bromleyana—South Pacific near Sydney and New Zealand, 400 to 1100 fathoms.
Nebaliopsis typica—Mid South Pacific, 2550 fathoms.
Pseudomma sarsii—Near Kerguelen, 120 fathoms.
Pagurodes inarmatus—South Pacific near New Zealand, 1100 fathoms.
Colossendeis gigas—Eastern South Pacific, 1375 fathoms.
„ *leptorhynchus*—Eastern South Pacific, 1375 fathoms, and Magellan Strait, 400 fathoms.
Amussium meridionale—Eastern South Pacific, 1450 fathoms.
Silenia sarsii—Western South Atlantic, 2650 fathoms.
Pleurotoma (*Surcula*) *staminea*—Near Kerguelen, 105 fathoms.
Cirroteuthis magna—Eastern South Pacific, 2225 fathoms.
Eledone rotunda—Eastern South Pacific, 2225 fathoms.
Farciminaria magna—Western South Atlantic, 1900 and 2650 fathoms.
Onchopora sinclairii—Near Kerguelen and Heard Islands, 28 to 150 fathoms; Australia.
Corynascidia suhmi—Eastern South Pacific, 2160 fathoms.
Antimora rostrata—Western South Atlantic, 600 fathoms.
Cyema atrum—Eastern South Pacific, 1500 fathoms.
Macrurus filicauda—Eastern South Pacific and Western South Atlantic, 1900 to 2650 fathoms.

LIST I *d*.

In the second place we give a list of the 24 species which are known to occur in regions both south and north of the tropics, but which have not hitherto been recorded from the intervening tropical zone. From the distributional notes accompanying each species it will be observed that 15 of the species are true deep-sea forms, being unknown from depths less than 1000 fathoms; other 7 species, though found in depths over 1000 fathoms in the region represented by these eight Stations, occur outside this region in depths less than 1000 fathoms, and 4 of these species are recorded from shallow water under 150 fathoms; the depths for 2 of the species outside the area under consideration are unrecorded.

Axinella erecta—Near Crozet, Marion, and Tristan Islands, 90 to 550 fathoms; North Atlantic.
Aulocalyx irregularis—Near Marion Island, 310 fathoms, and North Atlantic, 1075 fathoms.
Cereus spinosus—Western North Pacific near Japan, 1875 fathoms.
Liponema multiporum—Magellan Strait, 125 to 160 fathoms, and Western North Pacific, 1875 fathoms.
Antedon abyssicola—Western North Pacific, 2900 fathoms.
Pontaster forcipatus—Western North Atlantic, 1240 to 1700 fathoms.
Ophiernus vallincola—Mid North Atlantic near Azores, 1000 fathoms.
Ophiocten hastatum—South Pacific near New Zealand and Mid North Atlantic, 1100 and 1000 fathoms.
Pourtalesia phiale—North Atlantic ("Porcupine" and "Valorous"), 1215 fathoms.
Elpidia glacialis—North Atlantic (Norw. N. Atl. Exp.) and Kara Sea, 50 to 150 fathoms (Swed. Arct. Exp.).

Holothuria thomsoni—Western North Pacific, 1875 and 2900 fathoms.
Kolga nana—Western North Atlantic, 1250 fathoms.
Lætmogone wyville-thomsoni—Eastern South Pacific, 1375 fathoms, and off Japan, 345 fathoms.
Pelagonemertes rollestoni—Near Japan, 420 to 775 fathoms.
Eurycope fragilis—Western North Pacific, 1875 fathoms.
Boreomysis scyphops—North Atlantic and Arctic, depth (?).
Gnathophausia gigas—Mid North Atlantic, 2200 fathoms.
Munidopsis antonii—Eastern South Pacific, 1375 fathoms; North-West Africa, 2187 fathoms.
„ *subsquamosa*—Eastern South Pacific and Western North Pacific, 1450 and 1875 fathoms.
Trochus (*Margarita*) *infundibulum*—Western North Atlantic (Bermuda), 1075 fathoms.
Idmonea marionensis—Near Marion and Heard Is., and off R. Plate, 50 to 600 fathoms; Mediterranean and Australia.
Halosaurus macrochir—Eastern North Atlantic (Portugal), 1090 fathoms.
Stomias boa—Mediterranean and South Pacific, depth (?).
Synaphobranchus bathybius—Western North Pacific, 1875 and 2050 fathoms.

LIST I *e*.

In the third place we give a list of the 12 species which are known to occur in regions both south of and within the tropics, but which have not hitherto been recorded from regions north of the tropic of Cancer. From the distributional notes accompanying each species it will be observed that 5 of the species are true deep-sea forms, being unknown from depths less than 1000 fathoms; the other 7 species, though found in depths over 1000 fathoms in the region represented by these eight Stations, occur outside this region in depths less than 1000 fathoms, and 1 of these species is recorded from shallow water under 150 fathoms.

Corallimorphus rigidus—Eastern South Pacific and Western tropical Pacific, 2160 and 1425 fathoms.
Atolla wyvillei—Western South Atlantic, 2040 fathoms; Indian Ocean, 240 to 405 fathoms.
Hyocrinus bethellianus—Mid tropical Atlantic and Western tropical Pacific, 1850 and 2325 fathoms.
Hymenaster nobilis—Indian Ocean, 1748 fathoms.
Ophiacantha cosmica—Mid South Atlantic and Eastern South Pacific, 1000 to 2225 fathoms; Western tropical Atlantic, 350 fathoms; Western tropical Pacific, 800 and 1070 fathoms.
Goniocidaris canaliculata—Near Heard, Kerguelen, and Falkland Islands; Natal, Zanzibar, Australia, shore to 1975 fathoms.
Macrocypris similis—Magellan Strait, 165 fathoms; tropical Atlantic near Brazil and Ascension, 675 and 420 fathoms.
Serolis antarctica—Western tropical Atlantic near Brazilian coast, 400 fathoms.
Bentheuphausia amblyops—Mid South Atlantic and mid tropical Atlantic, 1000 and 1500 fathoms.
Salicornaria magnifica—Western South Atlantic and mid tropical Atlantic, 1900 fathoms, and Western tropical Atlantic, 350 fathoms.
Culeolus recumbens—Indian Ocean, 1997 fathoms.
Melamphaës crassiceps—Mid tropical Atlantic and Western tropical Pacific, 1500 and 1100 fathoms, and Western tropical Atlantic, 675 fathoms.

LIST I *f*.

In the fourth place we give a list of the 17 widely-distributed species which are known to occur both in tropical and each of the extra-tropical regions. From

the distributional notes accompanying each species, it will be observed that 5 of the species are true deep-sea forms, being unknown from depths less than 1000 fathoms; the other 12 species, though found in depths over 1000 fathoms in the region represented by these eight Stations, occur outside this region in depths less than 1000 fathoms, and 6 of these species are recorded from shallow water under 150 fathoms.

Four of the species (viz., *Bathyactis symmetrica*, *Cythere dasyderma*, *Cythere dictyon*, and *Gonostoma microdon*) appear to be almost cosmopolitan, occurring in all regions of the ocean, and in all depths from relatively shallow to very deep water.

Stylocordyla stipitata—Off Kerguelen, Marion Island, Bahia and Nova Scotia, 7 to 140 fathoms; also Eastern North Atlantic and Grenada.

Bathyactis symmetrica—North, tropical and South Atlantic, North, tropical and South Pacific, 32 to 2900 fms.

Oneirophanta mutabilis—Eastern South Pacific, Western South Atlantic, mid tropical Pacific, and Western North Pacific, 2160 to 2900 fathoms.

Pseudostichopus villosus—Eastern South Pacific, Western South Atlantic, Western tropical Pacific, Western North Pacific, and Western North Atlantic, 1450 to 2900 fathoms.

Lætmonice producta—Off Marion, Kerguelen, and Heard Is., New Zealand, and Nova Scotia, 20 to 700 fathoms; mid South Atlantic, mid North Atlantic, Western tropical Pacific, and Western North Pacific, 1400 to 2900 fathoms.

Cythere acanthoderma—Western tropical Pacific, 580 fathoms; Eastern South Pacific, Western North Pacific, and mid North Atlantic, 1000 to 2750 fathoms.

„ *dasyderma*—Magellan Strait, South, tropical and North Atlantic, South, tropical and North Pacific, 150 to 2740 fathoms.

„ *dictyon*—Off Heard Island, Magellan Strait, South, tropical and North Atlantic, South, tropical and North Pacific, 37 to 2750 fathoms.

Cytheropteron mucronalatum—Eastern South Pacific, Western tropical Pacific, Western North Pacific, and mid North Atlantic, 1375 to 2050 fathoms.

Krithe producta—Off Marion Island, Magellan Strait, South, tropical and North Atlantic, South and tropical Pacific, 50 to 1825 fathoms.

Eucopia australis—Eastern and mid tropical Atlantic, Western and mid North Atlantic, and Western North Pacific, 1000 to 1975 fathoms; original specimen from stomach of penguin in Antarctic regions.

Hymenodora mollicutis—Western and mid South Atlantic, mid tropical Atlantic, and Eastern North Atlantic, 1675 to 2500 fathoms.

Nematocarcinus proximatus—Eastern South Pacific and Western North Pacific, 1375 to 1875 fathoms, and Arafura Sea, 28 fathoms.

Bugula reticulata—Magellan Strait, 175 fathoms; Western South Atlantic, 600 fathoms; and Eastern South Pacific, mid tropical Atlantic, and mid North Atlantic, 1850 to 2500 fathoms.

Terebratula wyvillii—Eastern South Pacific, Western South Atlantic, Western tropical Pacific, and Western North Pacific, 1035 to 2900 fathoms.

Gonostoma microdon—South, tropical and North Atlantic, South, tropical and North Pacific, 500 to 2900 fms.

Macrurus armatus—Mid tropical Pacific and Western North Pacific, 2425 and 2050 fathoms; South Pacific near New Zealand, 400 fathoms.

We may now summarise the distribution of these 91 species which extend into other regions of the ocean outside the area represented by these eight Stations, as follows:—

Bathymetrical Distribution.—It appears that of these 91 species, 51 species are known to occur only in depths greater than 1000 fathoms, while 38 species are recorded

from above and below the 1000 fathoms line (of which 19 species extend into shallow water less than 150 fathoms—see list below), the depths from which the remaining 2 species were obtained outside the region under consideration being unrecorded.

LIST I *g*.

We give here the names of the 19 species which extend from deep water over 1000 fathoms into shallow water under 150 fathoms, one of which is recorded from the shore :—

Axinella erecta.
Stylocordyla stipitata.
Liponema multiporum.
Bathyactis symmetrica.
Porania antarctica.
Ophiocten amitinum.
Echinus magellanicus.
Goniocidaris canaliculata (shore).
Schizaster moseleyi.
Elpidia glacialis.
Lætmonice producta.
Cythere dictyon.
Krithe producta.
Arcturus furcatus.
Pseudomma sarsii.
Nematocarcinus proximatus.
Pleurotoma (*Surcula*) *staminea.*
Idmonea marionensis.
Onchopora sinclairii.

Geographical Distribution.—Of the 91 species we find that :—

43	species	are	represented	in the South Pacific area,
27	,,	,,	,,	North Atlantic ,,
25	,,	,,	,,	South Atlantic ,,
22	,,	,,	,,	North Pacific ,,
18	,,	,,	,,	Kerguelen Region,
17	,,	,,	,,	Tropical Pacific area,
16	,,	,,	,,	Tropical Atlantic ,,
9	,,	,,	,,	Magellan Strait,
4	,,	,,	,,	Tropical Indian Ocean,
2	,,	,,	,,	Arctic area.

These terms are used collectively, and include the various regions within the area indicated ; for instance, the South Pacific area includes New Zealand and the south-east of Australia, although the great majority of the species occur in the eastern portion of that area off the coast of South America.

LIST I *h*.

In the foregoing notes the distribution of each species has been considered as a whole, including all varieties. Were the distribution of each variety to be looked upon as distinct, certain modifications would be made, as will be seen from the following list of species with varieties represented in the area under consideration (which is here designated Kerguelen Region), the geographical distribution of each variety being briefly indicated :—

Stylocordyla stipitata—North and tropical Atlantic and Southern Ocean (Kerguelen region).
„ var. *globosa*—Marion and Kerguelen Islands.
Pontaster forcipatus—North Atlantic.
„ var. *echinata*—Southern Ocean (Kerguelen region).
Benthodytes sanguinolenta—South Pacific.
„ var. *marginata*—Southern Ocean (Kerguelen region).
Cucumaria abyssorum—Southern Ocean (Kerguelen region).
„ var. *grandis*—South Pacific.
„ var. *hyalina*—South Pacific and Southern Ocean (Kerguelen region).
Holothuria thomsoni—North Pacific.
„ var. *hyalina*—Southern Ocean (Kerguelen region).
Pseudostichopus villosus—North and South Atlantic, North, tropical and South Pacific, and Southern Ocean (Kerguelen region).
„ var. *violaceus*—Southern Ocean (Kerguelen region).
Psychropotes longicauda—South Pacific and Southern Ocean (Kerguelen region).
„ var. *fusco-purpurea*—Southern Ocean (Kerguelen region).
„ var. *monstrosa*—Southern Ocean (Kerguelen region).
Lætmonice producta—Kerguelen and Heard Islands.
„ var. *assimilis*—Nova Scotia.
„ var. *benthaliana*—North Pacific and Southern Ocean (Kerguelen region).
„ var. *willemoesi*—North and South Atlantic, tropical and South Pacific, and Southern Ocean (Kerguelen region).
„ var. *wyvillei*—Marion Island and Southern Ocean (Kerguelen region).
Munidopsis subsquamosa—North Pacific.
„ var. *aculeata*—South Pacific and Southern Ocean (Kerguelen region).
Bugula reticulata—South Atlantic, South Pacific, Magellan Strait, and Southern Ocean (Kerguelen region).
„ var. *unicornis*—North and tropical Atlantic.
Farciminaria magna—South Atlantic and Southern Ocean (Kerguelen region).
„ var. *armata*—South Atlantic.

LIST I*i*.

Turning now our attention for a moment to the genera represented at these eight Stations in the Southern Indian Ocean, we find that out of the total number of genera (186) 30 genera (or 16 per cent.) are known up to the present time only from the region under consideration. We give here a list of these 30 genera, from which it will be observed that the great majority include only a single species, there being in fact only 2 genera (*Ophioplinthus* and *Abyssascidia*) each containing 2 species, and that the great majority occur at a single Station; 3 of the genera, were, however, represented each at two Stations, while 1 genus (*Grubianella*) was found at three Stations.

Meliiderma (contains 1 species taken at a single Station).
Balanella (contains 1 species taken at a single Station).
Pleorhabdus (contains 1 species taken at a single Station).
Callozostron (contains 1 species taken at a single Station).
Tealidium (contains 1 species taken at a single Station).
Halisiphonia (contains 1 species taken at a single Station).
Pectis (contains 1 species taken at a single Station).
Periphema (contains 1 species taken at a single Station).
Thamnostylus (contains 1 species taken at a single Station).

Thaumatocrinus (contains 1 species taken at a single Station).
Chitonaster (contains 1 species taken at a single Station).
Ophiocymbium (contains 1 species taken at a single Station).
Ophioplinthus (contains 2 species taken at the same Station).
Echinocrepis (contains 1 species taken at a single Station).
Genicopatagus (contains 1 species taken at a single Station).
Spatagocystis (contains 1 species taken at two Stations).
Scotoanassa (contains 1 species taken at a single Station).
Prothelmins (contains 1 species taken at a single Station).
Grubianella (contains 1 species taken at three Stations).
Stelechopus (contains 1 species taken at a single Station).
Valettia (contains 1 species taken at a single Station).
Iolanthe (contains 1 species taken at a single Station).
Chalaraspis (contains 1 species taken at a single Station).
Petalidium (contains 1 species taken at two Stations).
Guivillea (contains 1 species taken at a single Station).
Abyssascidia (contains 2 species taken at two Stations).
Fungulus (contains 1 species taken at a single Station).
Pharyngodictyon (contains 1 species taken at a single Station).
Bathydraco (contains 1 species taken at a single Station).
Melanonus (contains 1 species taken at a single Station).

LIST I*k*.

We may also draw attention to the following 10 genera which, though not limited to the region represented by these eight Stations, are known to occur only in regions south of the southern tropic. With two exceptions (*Foveolaria* and *Onchopora*) they are all deep-sea genera unknown from depths less than 1000 fathoms. The number of species contained in each genus, and the geographical and bathymetrical distribution of each genus, are briefly indicated:—

Leptopenus	(containing	2	species),	South Pacific, South Atlantic, 1600 to 2160 fathoms.
Scotoplanes	(	,,	7	,,),	South Atlantic, South Pacific, Cape, 1260 to 2650 fathoms.
Maldanella	(	,,	3	,,),	South Pacific, 1100 to 2225 fathoms.
Acanthocope	(	,,	2	,,),	South Pacific, 1450 to 1800 fathoms.
Nebaliopsis	(	,,	1	,,),	South Pacific, 1375 to 2550 fathoms.
Silenia	(	,,	1	,,),	South Atlantic, 1950 to 2650 fathoms.
Foveolaria	(	,,	4	,,),	South Pacific, South Atlantic, Simon's Bay, shallow water to 1600 fathoms.
Onchopora	(	,,	1	,,),	Southern Islands, South Pacific, 28 to 1950 fathoms.
Corynascidia	(	,,	1	,,),	South Pacific, 1375 to 2160 fathoms.
Bathylagus	(	,,	2	,,),	South Atlantic, 1950 to 2040 fathoms.

LIST II.

METAZOA PROCURED BY THE CHALLENGER IN THE OTHER DEEP-WATER AREAS OF THE SOUTHERN HEMISPHERE SOUTH OF THE TROPIC OF CAPRICORN, IN DEPTHS EXCEEDING 1000 FATHOMS, EXCLUDING THOSE FROM THE DEEP-WATER AREA OF THE KERGUELEN REGION.

For the purposes of comparison we have divided the deep-water areas of the Southern Hemisphere into two categories, viz.: (1) the deep-water area of the Kerguelen Region, and (2) the remainder of the deep-water areas of the Southern Hemisphere. We have already treated fully of the marine Metazoa from the deep-water area of the Kerguelen Region (see List I.), and will now proceed to consider the marine Metazoa from the remaining deep-water areas of the Southern Hemisphere; to avoid repetition we have omitted forty-eight species which occur in both these divisions,[1] particulars of which will be found in Lists I*c.*, I*d.*, I*e.*, I*f.*

This list (List II.) contains all the species and varieties of marine Metazoa described and recorded in the Challenger Report from twenty-nine deep-water Stations in the Southern Hemisphere, lying between latitude 24° 38′ to 48° 37′ S., the depths varying from 1000 to 2650 fathoms, with the exception of the forty-eight species above referred to, so that by adding together Lists I. and II. we have a complete list of all the species of marine Metazoa known up to the present time from deep water in the Southern Hemisphere in depths exceeding 1000 fathoms. These twenty-nine Stations are on the whole further north than the eight Stations treated of in List I., and were not nearly so productive. Fifteen of the Stations (viz., Nos. 133, 134, 135, 137, 143, 317, 318, 323, 325, 331, 332, 333, 334, 335, and 337) are situated in the Southern Atlantic Ocean, and the remaining fourteen Stations (viz., Nos. 165, 168, 285, 286, 289, 291, 293, 295, 296, 297, 298, 299, 300, and 302) are situated in the Southern Pacific Ocean. The trawl was used at twenty-two of these Stations, the dredge being sent down at the other seven Stations. The species not known to occur to the north of the southern tropic are indicated in this list by an asterisk *.

DEEP-SEA KERATOSA:

**Holopsamma argillaceum*, Haeckel.
**Psammina plakina*, Haeckel.

[1] Viz., *Corallimorphus rigidus*, *Bathyactis symmetrica*, *Leptopenus discus*, *Atolla wyvillei*, *Pararchaster pedicifer*, *Ophiacantha cosmica*, *Ophiocten hastatum*, *Ophioglypha lacazei*, *Cystechinus vesica* and *wyvillii*, *Pourtalesia carinata* and *ceratopyga*, *Urechinus naresianus*, *Benthodytes sordida*, *Lætmogone wyville-thomsoni*, *Oneirophanta mutabilis*, *Pseudostichopus villosus*, *Psychropotes longicauda*, *Scotoplanes globosa*, *Hyalinœcia benthaliana*, *Lætmonice producta*, *Nothria abranchiata* (=*abyssicola*), *Cythere acanthoderma* and *dasyderma* and *dictyon*, *Cytheropteron mucronalatum*, *Krithe producta*, *Serolis bromleyana*, *Nebaliopsis typica*, *Bentheuphausia amblyops*, *Hymenodora mollicutis*, *Nematocarcinus proximatus*, *Munidopsis antonii* and *subsquamosa*, *Pagurodes inarmatus*, *Colossendeis gigas* and *leptorhynchus*, *Amussium meridionale*, *Silenia sarsii*, *Cirroteuthis magna*, *Eledone rotunda*, *Bugula reticulata*, *Salicornaria magnifica*, *Terebratula wyvillii*, *Corynascidia suhmi*, *Cyema atrum*, *Gonostoma microdon*, and *Macrurus filicauda*.

MONAXONIDA :

**Axoniderma mirabile*, Ridley and Dendy.
**Cladorhiza inversa*,[1] Ridley and Dendy.
Esperella biserialis,[2] Ridley and Dendy.
Phakellia[3] *ventilabrum*[4] (Johnston), var. *connexiva*, Ridley and Dendy.
**Tedania*[5] *actiniiformis*,[6] Ridley and Dendy.
**Trichostemma*[7] *irregularis*, Ridley and Dendy.

TETRACTINELLIDA :

**Thenea wrightii*, Sollas.
,, sp. (?).

HEXACTINELLIDA :

**Bathydorus baculifer*, Schulze.
**Caulocalyx tener*, Schulze.
**Holascus stellatus*, Schulze.

[1] The most remarkable feature about *Cladorhiza inversa* concerns its external form; compared with other "*Crinorhiza*" forms it appears to be upside down; nor can we be certain that the surface which we have called "lower" in the description is not really the upper, and *vice versa*.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 94.)

[2] *Esperella biserialis* forms a most interesting and important link between the two genera *Esperella* and *Cladorhiza*, especially as regards external form. It is also particularly interesting in that it exhibits a distinctly bilateral symmetry.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 76.)

[3] We have thought it desirable in the case of the genus *Phakellia* to make use of external form as a generic character, otherwise we know of no character which would serve to separate the genus *Phakellia* from the genus *Axinella*.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 170.)

[4] *Phakellia ventilabrum* is typically an inhabitant of deep water, being common in depths over 100 fathoms, seldom occurring in shallower water, and going down to 1035 fathoms, as shown by the Challenger dredgings.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 171.)

[5] The range of external form exhibited by the genus *Tedania* is shown by the Challenger dredgings to be a very remarkable one indeed; hitherto known only by more or less massive or digitate specimens, we have had to add to the genus two new species, *T. infundibuliformis* and *T. actiniiformis*, characterised by very specialised, though quite different, external forms; the former being funnel-shaped, and the latter "actiniiform" (like an Actinia) with oscular projections on the top and a definite zone of pores. The species of this genus are very difficult to separate satisfactorily from one another; future researches may, very probably, by the discovery of intermediate forms, render possible the union of some which are at present described as distinct.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 50–51.)

[6] *Tedania actiniiformis* is a very important and well-characterised species; it is distinguished from all previously known by its external form and the arrangement of the pores in a definite zone. Its stylote spicule is the largest in the genus. It affords a really splendid instance of the manner in which sponges, which are shapeless masses when occurring in shallow water, assume in abyssal depths (in this case 2160 fathoms) a definite, symmetrical external form; this is its chief interest, for the species of the genus hitherto known, from comparatively shallow water, are, *par excellence*, amorphous sponges.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 56.)

[7] The original type of the genus *Trichostemma* is *Trichostemma hemisphæricum*, which occurs not rarely at Lofoten in a depth of 120 to 300 fathoms on soft clay bottom. The Challenger adds two new species, both from a very great depth and a bottom of ooze or mud. It is essentially a deep-sea genus, and affords another example of the manner in which deep-sea sponges commonly assume a definite, symmetrical external form. In this case, however, the object of the flattened form and the long radiating spicules is obvious, namely, as pointed out by SARS, to support the animal in the soft mud on which it lies; in our new species, *Trichostemma sarsii*, this arrangement is brought to a much greater degree of perfection than in the original type of the genus. The genus has a very wide geographical range, being found in deep water off the north of Scotland, coast of Norway, Arctic Sea, Gulf of St Lawrence, off the Azores, N.E. coast of Australia, and W. coast of South America.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 217.)

**Hyalonema poculum*, Schulze.
„ *tenue*, Schulze.
„ (*Stylocalyx*) *tenerum*, Schulze.
„ sp. (?).
**Hyalostylus dives*, Schulze.
**Trachycaulus gurlittii*, Schulze.
Dictyonine undetermined.

PENNATULIDA :
**Anthoptilum simplex*, Kölliker.

ANTIPATHARIA :
**Schizopathes crassa*,[1] Brook.

ACTINIARIA :
**Aulorchis paradoxa*,[2] Hertwig.
**Corallimorphus profundus*, Moseley.
Edwardsia sp. (?).
**Epizoanthus thalamophilus*, Hertwig.
**Ophiodiscus annulatus*, Hertwig.
* „ *sulcatus*, Hertwig.
Palythoa (?) sp.
**Paractis excavata*,[3] Hertwig.
Phellia (?) sp.
**Polyopis striata*,[4] Hertwig.
**Polystomidium patens*,[5] Hertwig.
Actinian undetermined.

[1] The single specimen on which the species *Schizopathes crassa* is based is the finest example of the Schizopathinæ contained in the Challenger collection. The stem is 57 cm. long, gracefully but gently flexuose, with a peculiar flattened sickle-like base replacing the rounded horny disc by which the Antipathinæ are attached to stones and other objects. In this case the species is probably fixed by the base being embedded in the mud constituting the bottom deposit in the area in which it occurs. The specimen is 53 cm. high, and measures 53 cm. also across the lower branches. The stem is simple, much flattened below, but gradually becoming cylindrical and slightly tapering above the lower branches.—(BROOK, *Zool. Chall. Exp.*, part 80, p. 147.)

[2] *Aulorchis paradoxa* is a form of great interest as enlarging by a new genus and species the group of forms devoid of tentacles. Unluckily, I have had but the one solitary specimen for study, and even this was badly preserved, and had apparently suffered much from the dredge. . . . From my description it may be recognised that *Aulorchis* is one of the most interesting Actiniæ, and that it would be very desirable that a richer material of it should be acquired by fresh deep-sea investigations.—(HERTWIG, *Zool. Chall. Exp.*, part 71, pp. 21, 24.)

[3] *Paractis excavata* is one of the most characteristic forms of the Challenger material, both as to the shape of the body, and as to its finer structure.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 41.)

[4] The small Actinia without tentacles, which I call *Polyopis striata*, was probably sac-shaped during life; its rounded posterior end probably stuck in the mud, whilst its broad anterior end formed by the oral disk projected freely.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 101.)

[5] In *Polystomidium patens* the tentacles have undergone retrograde formation to an extent which has hitherto been observed only in the genus *Polyopis;* the only traces of them are the terminal openings, which lead directly into the radial chambers and are surrounded by swollen margins, the remains of the tentacle wall. In their habit of body, in the endodermal position of the circular muscle, and in the presence of the marginal spherules, these animals are allied to the Antheadæ.—(HERTWIG, *Zool. Chall. Exp.*, part 15, p. 67.)

CORALS :

Deltocyathus italicus,[1] M.-Edwards and Haime.
**Leptopenus hypocælus*, Moseley.
Solenosmilia variabilis,[2] Duncan.

DEEP-SEA MEDUSÆ :

**Leonura terminalis*, Haeckel.
**Nauphanta challengeri*, Haeckel.
**Periphylla mirabilis*, Haeckel.
**Tesserantha connectens*, Haeckel.

SIPHONOPHORÆ :

**Anthemodes articulata*, Haeckel.
**Bathyphysa gigantea*, Haeckel.

CRINOIDEA :

**Rhizocrinus*[3] *lofotensis*,[4] Sars.

ASTEROIDEA :

Dytaster exilis,[5] Sladen.
" " var. *gracilis*, Sladen.
* " *nobilis*, Sladen.
Freyella benthophila, Sladen.
**Hymenaster anomalus*, Sladen.

I have little to add to the very full accounts of the many varieties of *Deltocyathus italicus* contained in the memoirs cited. . . . It is very remarkable that none of the specimens obtained by us were attached, and that only one shows any trace of ever having been attached. This one specimen [from Station 285, South Pacific, 2375 fathoms], however, is large, and though somewhat imperfect, has a most distinct pedicle and scar of attachment, and evidently remained fixed up to a period of full maturity.—(MOSELEY, *Zool. Chall. Exp.*, part 7, pp. 145, 146.)

[2] *Solenosmilia variabilis* is a very widely-spread and characteristic deep-sea form, and varies exceedingly. Many specimens dredged by us were dead, old, and much broken, but always recognisable by the peculiar mode of branching and the texture of the cœnenchym.—(MOSELEY, *Zool. Chall. Exp.*, part 7, p. 181.)

[3] Of the stalked Crinoids *Rhizocrinus* has the farthest northern range (68° N.), but it has not been met with more than once (Station 122), or possibly twice (Station 323), south of the equator, and is limited to the Atlantic and Caribbean Ocean.—(CARPENTER, *Zool. Chall. Exp.*, part 32, p. 136.)

[4] The form of the calyx in this species [*Rhizocrinus lofotensis*] varies very considerably ; for it is nearly hemispherical in some specimens and much elongated in others. These last have the best developed arms ; and to some extent, therefore, the forms with a low and wide cup must be regarded as premature. But differences of development will not entirely account for the variation, as the calyx of a young specimen found by SARS is distinctly higher (longer) than broad.— (CARPENTER, *Zool. Chall. Exp.*, part 32, p. 261.)

[5] Of *Dytaster exilis* and its two varieties, *carinata* and *gracilis*, SLADEN writes :—The variety *carinata* resembles the type more nearly than the variety *gracilis* does. The wide separation of the geographical positions of the type and its two varieties is of the greatest interest, and bears evidence to the enormous range of the *Dytaster exilis* form, and of the comparatively small amount of variation exhibited by this type in what may well be spoken of as extreme limits of position. The type comes from the Pacific, off the western coast of South America, the nearly allied variety *carinata* from the North Atlantic, off the eastern coast of the United States of America, whilst the more divergent variety—if, indeed, it be not a distinct species—was dredged in the South Atlantic, westward of Tristan da Cunha.—(*Zool. Chall. Exp.*, part 51, p. 70.)

**Hymenaster carnosus*, Sladen.
* ,, *echinulatus*, Sladen.
* ,, *geometricus*, Sladen.
* ,, *pergamentaceus*, Sladen.
* ,, *porosissimus*, Sladen.
* ,, *vicarius*, Sladen.
**Hyphalaster diadematus*, Sladen.
Marsipaster hirsutus, Sladen.
* ,, *spinosissimus*, Sladen.
**Pontaster pristinus*, Sladen.
**Porcellanaster crassus*, Sladen.
* ,, *eremicus*, Sladen.
* ,, *gracilis*, Sladen.
**Pythonaster murrayi*,[1] Sladen.

OPHIUROIDEA :

**Amphilepis patens*, Lyman.
**Amphiura dalea*, Lyman.
**Ophiacantha sentosa*, Lyman.
**Ophiactis poa*, Lyman.
**Ophiocten umbraticum*, Lyman.
Ophioglypha bullata, Wyville Thomson.
,, *irrorata*, Lyman.
* ,, *jejuna*, Lyman,
* ,, *meridionalis*,[2] Lyman.
,, *ornata*, Lyman.
,, sp. (?).
Ophiomastus tegulitius, Lyman.
**Ophiomusium archaster*, Wyville Thomson (MS.), Lyman.
,, *armigerum*, Lyman.
,, *lymani*,[3] Wyville Thomson.
**Ophiomyces*[4] *grandis*, Lyman.

[1] This remarkable and abnormal type of Asterid [*Pythonaster murrayi*] is altogether unlike any other form. Its general morphological structure appears to me to justify its inclusion in the family Pterasteridæ. Its aberrant peculiarities, however, necessitate in my opinion its separation in a distinct sub-family.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 531.)

[2] *Ophioglypha meridionalis* is the southern cousin of *Ophioglypha robusta*, from which it differs in shorter arm spines, more swollen disk scales, smaller mouth papillæ, and fewer tentacle scales.—(LYMAN, *Zool. Chall. Exp.*, part 14, p. 41.)

[3] The specimens [of *Ophiomusium lymani*] from the widely separated stations showed certain minor differences. For example, those from Station 235 [Japan] had more arm spines and rather more numerous lower disk plates, and the tentacle scales were entire, instead of divided. I have deemed it best to keep the varieties together for the present. —(LYMAN, *Zool. Chall. Exp.*, part 14, p. 90.)

[4] This singular genus [*Ophiomyces*] stands quite by itself, unless we compare its curious mouth papillæ with the spatula-like tentacle scales of *Ophiopsila*. All the specimens I have seen had a tendency to raise the arms above the

Ophiophyllum sp. (?).
Ophiothamnus sp. (?).
**Ophiotholia supplicans*, Lyman.
**Ophiozona stellata*, Lyman.

ECHINOIDEA :

Aceste bellidifera,[1] Wyville Thomson.
Aspidodiadema[2] *microtuberculatum*, Agassiz.
Brissopsis luzonica (Gray).
Cystechinus clypeatus,[3] Agassiz.
Echinus elegans (Düben and Koren).
**Phormosoma asterias*, Agassiz.
* ,, *hoplacantha*,[4] Wyville Thomson.
Pourtalesia laguncula, Agassiz.
Salenia hastigera, Agassiz.

disk, vertically ; which shows that the muscular tension must have some peculiar proportion. . . . The peculiar twisting upward of the arms and disk of *Ophiomyces* is explained by the absence of radial shields, a want not yet observed in any other genus. It seems, then, that one function of radial shields is to keep the disk in shape, somewhat like the action of the sticks of an umbrella.—(LYMAN, *Zool. Chall. Exp.*, part 14, pp. 240, 242.)

[1] At first glance *Aceste bellidifera* appears one of the most remarkable of Sea-urchins. . . . The enormous development of the sucker of the odd anterior ambulacrum is an eminently embryonic feature ; it exists in the youngest stages of all the Spatangoids of which we know the development. . . . The general outline of the test as seen both in profile and from above is strikingly similar to that of the Schizasteridæ. In fact, this genus is of the greatest interest, showing as it does striking affinities on the one side to the Schizasteridæ and other Spatangina, such as *Brissopsis*, and on the other to the Pourtalesiæ, not only in the structure of its ambulacral system, but also from the position and shape of the actinostome, and the more or less cylindrical test modified in its outline from its Schizasterid affinities.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 195–6.)

[2] *Aspidodiadema* is a most interesting genus, intermediate between the Cidaridæ proper and the Diadematidæ. It has like the latter a thin test, with long hollow primary spines nearly straight, and strongly verticillate, especially in the young. . . . The most remarkable feature of this genus is the structure of the ambulacral system.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 64–5.)

[3] The test of this species [*Cystechinus clypeatus*] is quite stout, judging from the thickness of the fragments preserved. In the specimens from the greatest depths at which this species has been found, the test is much thinner than in the fragments which are found near the 1000 fathom line. As a general rule among the Pourtalesiæ, the test of the different species having an extended bathymetrical range varies very materially in thickness, according to the depth at which the specimens were dredged, specimens of the same species from shallower regions having pretty generally a comparatively stouter test.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 149–150.)

[4] *Phormosoma hoplacantha* is the largest Sea-urchin with which I am acquainted. It measures no less than 312 mm. in diameter, and when fully expanded, must have been a striking object. This species is remarkable for the large size of the primary tubercles, arranged both on the actinal and abactinal surface of the interambulacral areas in horizontal rows ; on the abactinal surface they are distant, separated by large secondaries and miliaries, irregularly arranged on the coronal plates. . . . In alcohol the colour of the specimens of this species is dark violet, almost black both for the test and spines, and this formed a marked contrast to the white tips of the spines on the actinal surface. The existence of primary spines tipped with hoofs as in the Arbaciadæ is an interesting structural feature, connecting groups which thus far seemed somewhat isolated in their relationship to other Echinids. THOMSON speaks of the wear of the base of the cones as if they had been in use for "vigorous locomotion" over the ground, as we know to be the case in one of the species of *Arbacia* of the eastern North American coast. In the Echinothuridæ the conical tip does not extend along the sides of the extremity of the spine, forming, as in the Arbaciadæ, a kind of cap ; it is merely attached by a nearly horizontal base to the more flattened end of the spine. In consequence of this mode of attachment the tip is frequently lost.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 101-2.)

HOLOTHURIOIDEA :

**Benthodytes abyssicola*, Théel.
* „ *mamillifera*, Théel.
„ *papillifera*, Théel.
* „ *sanguinolenta*, Théel.
**Cucumaria abyssorum*, Théel, var. *grandis*, Théel.
**Elpidia verrucosa*, Théel.
**Enypniastes eximia*, Théel.
Euphronides depressa, Théel.
Holothuria murrayi, Théel.
**Pælopatides confundens*, Théel.
**Parelpidia cylindrica*, Théel.
* „ *elongata*, Théel.
**Peniagone vitrea*, Théel.
Psychropotes semperiana, Théel.
**Scotoplanes albida*, Théel.
* „ *papillosa*, Théel.
**Stichopus* (?) *torvus*, Théel.
Trochostoma sp. (?).
Two Holothurians undetermined.

NEMERTEA :

**Cerebratulus angusticeps*, Hubrecht.

GEPHYREA :

**Phascolosoma catherinæ*,[1] Müller.

ANNELIDA :

**Amphicteis sarsi*, M'Intosh.
Buskiella abyssorum, M'Intosh.
**Eumenia reticulata*, M'Intosh.
**Eunoa opalina*,[2] M'Intosh.
Eupista darwini, M'Intosh.
* „ *grubei*, M'Intosh.
**Euthelepus chilensis*, M'Intosh.

[1] Since FRITZ MÜLLER'S specimen [of *Phascolosoma catharinæ*] was labelled "Desterro," one may infer that it was not obtained in trawling, but was found on the shore during ebb tide. The specimen of the Challenger Expedition, on the other hand, was obtained from a very considerable depth. This difference of distribution is not, however, by any means unique, for other true Sipunculids exhibit a similar occurrence on the shore and at considerable depths.—(SELENKA, *Zool. Chall. Exp.*, part 36, p. 13.)

[2] An eyeless variety [of *Eunoa opalina*, Magellan Strait, Station 311, 245 fathoms] was trawled at Station 299, 2160 fathoms [S.E. Pacific]. It is of good size. The head is devoid of any trace of eyes, so that it forms another example of the influence of habitat on these important organs.—(M'INTOSH, *Zool. Chall. Exp.*, part 34, pp. 71–2.)

Leæna langerhansi, M'Intosh.
* „ *neo-zealaniæ*, M'Intosh.
Lumbriconereis abyssorum, M'Intosh.
Maldanella neo-zealaniæ, M'Intosh.
* „ *valparaisiensis*, M'Intosh.
Melinna armandi, M'Intosh.
Myriochele heeri, Malmgren.
Nothria ehlersi, M'Intosh.
* „ *pycnobranchiata*, M'Intosh.
Placostegus mörchii, M'Intosh.
„ *ornatus*, Sowerby.
Samythopsis grubei, M'Intosh.
Vermilia (?) sp.

OSTRACODA :

Argillæcia eburnea, Brady.
Bairdia hirsuta, Brady.
„ *victrix*, Brady.
Bythocypris elongata, Brady.
Crossophorus imperator, Brady.
Cythere dorsoserrata, Brady,
„ *irpex*, Brady.
* „ *normani*, Brady.
„ *scutigera*, Brady.
„ (?) *serratula*, Brady.
* „ *squalidentata*, Brady.
* „ *stolonifera*, Brady.
* „ *sulcatoperforata*, Brady.
Cytheropteron fenestratum, Brady.
Krithe tumida, Brady.
Pseudocythere[1] *caudata*, Sars.
Xestoleberis[2] *curta*, Brady.
„ *expansa*, Brady.

CIRRIPEDIA :

Scalpellum carinatum, Hoek.

[1] The genus *Pseudocythere* is widely distributed, occurring in the European seas as well as in distant regions of the southern hemisphere. As a fossil it has been recognised only in the Post-Tertiary deposits of the British Islands.—(G. S. BRADY, *Zool. Chall. Exp.*, part 4, p. 144.)

[2] The genus *Xestoleberis* is widely distributed, containing apparently a very large number of species, and occurring abundantly in the seas of all parts of the world. So far, however, as we know of it palæontologically, it would seem to be a genus of comparatively recent development.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 124.)

**Scalpellum darwinii*,[1] Hoek.
* „ *eximium*,[2] Hoek.
* „ *minutum*, Hoek.
„ *velutinum*,[3] Hoek.
**Verruca gibbosa*,[4] Hoek.
* „ *incerta*, Hoek.
* „ *quadrangularis*, Hoek.

AMPHIPODA :

**Andania abyssorum*,[5] Stebbing.
**Camacho bathyplous*, Stebbing.
**Cyphocaris micronyx*, Stebbing.
**Elasmopus subcarinata* (Haswell).
**Gammaropsis thomsoni*, Stebbing.
Lanceola, two species undetermined.
**Leucothoë tridens*, Stebbing.
**Œdiceroides cinderella*, Stebbing.
**Orchomene abyssorum*,[6] Stebbing.
**Podocerus hoeki*,[7] Stebbing (= *P. tuberculatus*, Hoek).
Stenopleura atlantica, Stebbing.

[1] *Scalpellum darwinii* is the largest species of *Scalpellum* known. Only a single specimen of it was dredged during the cruise of the Challenger attached to a manganese nodule.—(HOEK, *Zool. Chall. Exp.*, part 35, pp. 110–111.)

[2] Of this splendid species [*Scalpellum eximium*] only a single specimen was dredged, attached to a piece of pumice-stone.—(HOEK, *Zool. Chall. Exp.*, part 35, p. 100.)

[3] This beautiful species [*Scalpellum velutinum*] is represented by a single specimen. Provisionally there must be referred to the same species three smaller specimens, which were dredged near the southern point of Portugal ; yet I am not quite sure that they belong really to the same species. . . . The two Stations from which this species was obtained are both in the Atlantic ; the one (near Cape St Vincent) has about the same northern latitude as the other (north of Tristan da Cunha) has southern latitude.—(HOEK, *Zool. Chall. Exp.*, part 35, pp. 96, 99.)

[4] *Verruca gibbosa* is the largest and the most beautiful of the deep-sea species.—(HOEK, *Zool. Chall. Exp.*, part 35, p. 134.)

[5] The specific name [of *Andania abyssorum*] refers to the great depth from which this little creature was obtained, but is principally designed to call attention to its close relationship with the northern species *Andania abyssi*.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 742.)

[6] The specific name [of *Orchomene abyssorum*] has been given in allusion to the great depth from which the species is reported to have come. The single specimen was mounted during the voyage. Had this species been taken within any reasonable distance of *Orchomene musculosus*, the resemblance is so great that one might have been tempted to disregard the points of difference as due to some other cause than difference of species. It might be an accident that has caused one to be reported from the surface, and the other from so great a depth as 1900 fathoms, but that the Stations at which the two species were obtained are separated by nearly half the circumference of the globe is a circumstance not open to any such explanation.—(STEBBING, *Zool. Chall. Exp.*, part 67, pp. 678–9.)

[7] The specific name [of *Podocerus hoeki*] is given in compliment to Dr P. P. C. HOEK, who in 1882 gave a brief description and some figures of a new species, *Podocerus tuberculatus*, among the Crustacea of the "Willem Barents" Expedition. This species was obtained in lat. 71° 23′ N., long. 49° 38′ E., and judging only from the preliminary description and the figures of the two gnathopods, third uropods, and telson, presents an extraordinary resemblance to the Challenger species. . . . Considering the enormous distance between the places of capture, I have not thought it right to identify the two forms. Had they belonged to a single species of so wide a distribution, it is highly improbable that it would have escaped discovery for so long, and then suddenly have been discovered almost simultaneously at two enormously distant points.—(STEBBING, *Zool. Chall. Exp.*, part 67, pp. 1140–1.)

The single specimen [of *Podocerus tuberculatus*] described by Dr HOEK was taken in 1879 in lat. 71° 23′ N.,

ISOPODA:

**Acanthocope acutispina*, Beddard.
**Acanthomunna proteus*,[1] Beddard.
**Eurycope novæ-zelandiæ*, Beddard.
**Ischnosoma bacilloides*, Beddard.
**Munnopsis gracilis*, Beddard.
Neotanais americanus, Beddard.
**Serolis neæra*, Beddard.
,, sp. (?).

MACRURA:

Acanthephyra brachytelsonis, Bate.
,, *longidens*, Bate.
,, *sica*,[2] Bate.
Aristeus[3] *armatus*, Bate.
Benthesicymus altus, Bate.
,, *brasiliensis*, Bate.
* ,, *iridescens*, Bate.
* ,, *mollis*, Bate.
Gennadas intermedius, Bate.
,, *parvus*, Bate.
Glyphocrangon rimapes, Bate.

long. 49° 38′ E., from a depth of 67 fathoms. Other specimens were obtained on Sept. 6, 1881, in lat. 77° 7′ N., long. 49° 37′ E., from a depth of 170 fathoms. An examination of these has shown that the fingers of the gnathopods precisely agree in dentation with those of the specimen described in the Challenger Report under the name of *Podocerus hoeki*. That specimen was taken in the neighbourhood of New Zealand, July 8, 1874, in lat. 40° 28′ S., long. 177° 43′ E., and was supposed to come from a depth of 1100 fathoms. But though its habitat is separated by so vast a distance from the Arctic localities, there does not seem to be a single feature which can be relied on for distinguishing it from the species to which Dr HOEK had earlier given a name.—(STEBBING, "The Amphipoda collected during the voyages of the Willem Barents in the Arctic Seas in the years 1880–1884," *Bijdragen tot de Dierkunde*, Afl. 17, 1894, p. 45.)

[1] Two specimens of a deep-sea Isopod, belonging apparently to the same species [*Acanthomunna proteus*], are referred to this genus; they were dredged in 700 and 1100 fathoms respectively off New Zealand. The genus is remarkable for its dense spiny covering, a condition met with in other deep-sea and cold-water Isopoda. The specimens only differ from each other in colour; the larger specimen (from 1100 fathoms) is of a pale buff colour, the smaller of a rich brown.—(BEDDARD, *Zool. Chall. Exp.*, part 48, pp. 47–8.)

[2] *Acanthephyra sica* appears to be both abundant and widely distributed; it was taken by the Challenger at eleven Stations, more or less distant from one another,—in the Atlantic and Pacific Oceans, as far north as Japan, and as far south as New Zealand. Its bathymetrical range is also great, since it has been taken at a distance of from less than half a mile to about three miles from the surface of the ocean. It appears to be very prolific also, since some of the females that were captured carry a large number of small eggs.—(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 743).

[3] This genus [*Aristeus*] consists mostly of deep-water species, which swim freely in the sea, and during the cruise of the Challenger were never captured in less than 255 fathoms of water. . . . *Aristeus armatus* was captured at seven different localities at depths ranging from 1400 to 2350 fathoms. . . . Running down the eastern coast of South America, in the month of September 1873, the Challenger must have passed through a great multitude of young animals of this genus, varying in size from 4 to 14 mm., all of which bore evidence of belonging to allied species. The specimens corresponded closely excepting in such features as may be dependent upon age.—(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 311.)

Haliporus curvirostris, Bate.
**Hemipenæus speciosus*, Bate.
" *spinidorsalis*, Bate.
**Hepomadus inermis*, Bate.
**Notostomus murrayi*, Bate.
Pentacheles lævis, Bate.
Pontophilus gracilis, Bate.
* " *profundus*, Bate.
**Sergestes profundus*,[1] Bate.
Willemœsia leptodactyla (Willemoes-Suhm).

ANOMURA :

**Elasmonotus marginatus*, Henderson.
**Galacantha bellis*, Henderson.
Parapagurus abyssorum,[2] M.-Edwards.
**Tylaspis anomala*,[3] Henderson.

PYCNOGONIDA :

**Colossendeis brevipes*,[4] Hoek.
* " *media*, Hoek.
**Nymphon compactum*,[5] Hoek.
* " *longicollum*, Hoek.
* " *longicoxa*,[5] Hoek.
* " *procerum*, Hoek.

[1] The species of this genus [*Sergestes*] mostly live within 100 fathoms of the surface, but there is every reason to believe that this one [*Sergestes profundus*] resides near the bottom.—(SPENCE BATE, *Zool. Chall. Exp.*, part 52, p. 429.)

[2] A certain amount of variation is noticeable in specimens [of *Parapagurus abyssorum*] from different localities, more especially as regards the amount of pubescence and granulation on the chelipedes and ambulatory limbs. In a specimen from Station 133 [South Atlantic], the ophthalmic scales are bidentate, and the external prolongation of the second antennal peduncular joint is dentate. In spite of these apparent incongruities, an examination of the numerous specimens taken by the Challenger has convinced me that they all belong to a single species. . . . *Parapagurus abyssorum* is of special interest on account of its very extended distribution and deep-water habitat. It was taken by the Challenger in all the great ocean beds explored (with the exception of the Southern Ocean between the Cape and Australia), and nowhere in less than 1000 fathoms of water. [This species is recorded from Magellan Strait, 45 fathoms, but HENDERSON maintains that this is an error ; he says that a shallow-water habitat for the species is quite out of the question.] It appears to be invariably associated with an Anemone which exerts a solvent action on the Gastropod shell originally selected as a dwelling-place by the Hermit ; in many cases the shell has entirely disappeared, and in others it is greatly reduced, while the Anemone forms a soft and saccular covering on the exterior.—(HENDERSON, *Zool. Chall. Exp.*, part 69, p. 88.)

[3] The single specimen [of *Tylaspis anomala*] came from the greatest depth at which any Anomurous Crustacean was taken by the Challenger. The form of the abdomen points to the species having occupied some other dwelling-place than the Gastropod shell usually selected by the soft-tailed Pagurids.—(HENDERSON, *Zool. Chall. Exp.*, part 69, p. 81.)

[4] This true deep-sea species [*Colossendeis brevipes*] was dredged from the greatest depth at which a Pycnogonid has been found, viz., 2650 fathoms.—(HOEK, *Zool. Chall. Exp.*, part 10, p. 72.)

[5] I believe this species [*Nymphon longicoxa*] with its rudimentary eyes to form the transition from the shallow-water species to the true deep-sea species. . . . *Nymphon longicoxa* and *Nymphon compactum* were obtained [at the same Station] from a depth of 1100 fathoms. *N. longicoxa* shows rudimentary eyes, those of *N. compactum* are quite

LAMELLIBRANCHIATA :

Arca (*Barbatia*) *corpulenta*, Smith.
**Cryptodon moseleyi*, Smith.
Glomus nitens. Jeffreys
Lima (*Limatula*) sp. (?)
**Lyonsiella grandis*, Smith.
**Malletia pallida*, Smith.
**Venus* (*Chamelæa*) *mesodesma*, Quoy and Gaimard.

SCAPHOPODA AND GASTEROPODA :

**Basilissa simplex*, Watson.
**Clathurella cala*, Watson.
**Dentalium amphialum*, Watson.
,, *keras*, Watson.
Ianthina rotundata, Leach.
**Nassa dissimilis*, Watson.
**Pleurotoma* (*Spirotropis*) *aganactica*, Watson.
* ,, (*Thesbia*) *membranacea*, Watson.
* ,, (,,) *xanthias*, Watson.
**Stilifer brychius*, Watson.
Trochus sp. (?)

CEPHALOPODA :

**Histiopsis atlantica*, Hoyle.

POLYZOA :

Bicellaria naviculoris, Busk.
**Bugula margaritifera*,[1] Busk.
**Cellularia crateriformis*, Busk.
**Farciminaria cribraria*, Busk.
* ,, *magna*, Busk, var. *armata*, Busk.
Flustra biseriata, Busk.
Kinetoskias cyathus (Wyville Thomson).
,, *pocillum*, Busk.
**Menipea pateriformis*, Busk.

obsolete. *N. longicoxa* is one of the most slender, *N. compactum* one of the stoutest species dredged by the Challenger. In the one the auxiliary claws are wanting, whereas small ones are present in *N. longicoxa*, and in every other respect they are as widely different as two species of the same genus of Pycnogonids can be.—(HOEK, *Zool. Chall. Exp.*, part 10, pp. 39, 42).

[1] [*Bugula margaritifera* is] a very interesting form as coming from such an extreme depth. Its structure, as in most of the abyssal forms, is very delicate and transparent, and it is rooted by an infinite number of radical fibres, each attached to a dead Globigerina shell or similar small particle.—(BUSK, *Zool. Chall. Exp.*, part 30, p. 42.)

BRACHIOPODA :

Discina atlantica, King.
**Magasella flexuosa* (King).
**Waldheimia wyvillii*, Davidson.

TUNICATA :

Octacnemus bythius, Moseley.
Pyrosoma spinosum, Herdman.

FISHES :

**Bathylagus atlanticus*, Günther.
**Bathypterois longicauda*, Günther.
* „ *longipes*, Günther.
**Bathysaurus ferox*,[1] Günther.
**Chlorophthalmus gracilis*, Günther.
Ipnops murrayi,[2] Günther.
**Macrurus affinis*, Günther.
* „ *fernandezianus*, Günther.
* „ *murrayi*, Günther.

As in the case of List I., here again the great majority of the 253 species enumerated were each taken at only one of the twenty-nine Stations.

LIST II *a*.

Only 25 species occurred at more than one of these Stations, and of these 18 species were each represented at two Stations, and the remaining 7 species each at three Stations, as shown in the following list, where the number of Stations at which each species was found is indicated in brackets after the name of the species :—

[1] *Bathysaurus agassizii*, Goode and Bean, obtained at a depth of 647 fathoms in the Atlantic, lat. 33° 35′ N. long. 76° 0′ W., is probably not specifically distinct from the Pacific specimen [*Bathysaurus ferox* from Station 168, near New Zealand, 1100 fathoms]. It seems to be a fish with a somewhat deeper body, but, then, it was ascertained to be a "female, full of nearly mature eggs."—(GÜNTHER, *Zool. Chall. Exp.*, part 57, p. 183.)

[2] Ever since the discovery of this fish [*Ipnops murrayi*] much uncertainty has prevailed with regard to the nature and function of the extraordinary apparatus on the upper side of the head ; but from Professor MOSELEY'S examination it seems to be almost beyond doubt, that it is a special form of phosphorescent organ. The power of producing light, and thereby attracting other creatures, must be of great use to a fish, which, deprived of organs of sight and touch, would be unable to procure its food. The question of the homology of the luminous organ and its covering lamellæ is still obscure ; and no other specimen can be sacrificed to investigate the osteology of the skull. If, as Professor MOSELEY'S investigations seem to prove, the luminous organ is not a modification of the eye, as Mr MURRAY and myself supposed at first, and if the organ of vision with the optic nerve has disappeared, the luminous organ is probably the homologue of that which is found in some Scopelids between the eye and nostril, and the covering plates would be the homologues of the præorbital membrane bones. With the abortion of the eyes the luminous organs with their præorbitals would have moved from their usual lateral position to the top of the head.—(GÜNTHER, *Zool. Chall. Exp.*, part 57, pp. 190–1.)

Corallimorphus profundus (2).
Dytaster exilis (2).
Ophiomusium armigerum (2).
„ *lymani* (2).
Aspidodiadema microtuberculatum (3).
Cystechinus clypeatus (2).
Benthodytes mamillifera (2).
Cucumaria abyssorum (3).
Holothuria murrayi (2).
Pœlopatides confundens (3).
Nothria ehlersi (2).
„ *pycnobranchiata* (2).
Bairdia hirsuta (2).
Cyphocaris micronyx (2).
Acanthephyra sica (2).
Aristeus armatus (2).
Benthesicymus brasiliensis (3).
Glyphocrangon rimapes (2).
Pontophilus gracilis (2).
Sergestes profundus (2).
Willemœsia leptodactyla (3).
Parapagurus abyssorum (3).
Bugula margaritifera (2).
Cellularia crateriformis (2).
Chlorophthalmus gracilis (3).

The preceding list (List II.) of species from the deep-water areas of the Southern Hemisphere south of the southern tropic and outside of the Kerguelen Region, shows that in the regions of the Southern Hemisphere represented by the twenty-nine Stations referred to, the Challenger procured in depths exceeding 1000 fathoms representatives of 253 species and varieties of Metazoa, belonging to 182 genera. To these numbers must be added 48 species and 24 genera mentioned in footnote on page 36, not included in this list, having been already enumerated in the list (List I.) of species from the deep-water area of the Kerguelen Region. The proportion of genera to species in these twenty-nine Stations is exactly the same as in the eight Stations in the Kerguelen Region, viz., as 1 to 1·46. These twenty-nine Stations are situated on an average about seventeen degrees to the north of the mean latitude of the eight deep-water Stations in the Kerguelen Region, and it will be observed that, while 301 species were obtained at the twenty-nine Stations in the Southern Hemisphere outside the Kerguelen Region (or 10·4 species per haul), 272 species were taken at the eight Stations in the Kerguelen Region (or 34 species per haul).

An examination of the list shows that 19 of the species have received no specific names, and there is besides one variety as well as the species to which it belongs. As in the case of List I., and for reasons there stated, these must be deducted from the total number, leaving 233 distinct fully-described species the distribution of which may be discussed in detail.

These 233 species may be divided into (1) those that are known to occur only in the regions represented by these twenty-nine Stations; and (2) those that are known to occur in other regions situated northwards of the southern tropic.

a. *Species limited to the Southern Hemisphere south of the Tropic of Capricorn.*

In the first place we find that there are 165 species (or 65 per cent. of the total number[1] of species and varieties found at these twenty-nine Stations) which, as far as we know up to the present time, are limited in their distribution to regions south of the

[1] Not including the 48 species also occurring in the deep-water area of the Kerguelen Region (see footnote, p. 36).

southern tropic. These 165 species are indicated in the list by an asterisk, and little can be said about them beyond the fact that they are known only from the Southern Hemisphere, and (with the exception of 16 species referred to later on—see List II*g*.) from depths over 1000 fathoms.

LIST II *b*.

We enumerate here those species found at more than one of these Stations indicating in brackets the number of Stations at which each species was taken. It will be observed that the species limited to this area show a very restricted distribution within the area itself, for only 9 species were each taken at two Stations, and 3 species each at three Stations.

Corallimorphus profundus (2).
Benthodytes mamillifera (2).
Cucumaria abyssorum (3).
Pœlopatides confundens (3).
Nothria ehlersi (2).
„ *pycnobranchiata* (2).
Bairdia hirsuta (2).
Cyphocaris micronyx (2).
Sergestes profundus (2).
Bugula margaritifera (2).
Cellularia crateriformis (2).
Chlorophthalmus gracilis (3).

b. *Species extending outside the area under consideration.*

We come now to consider those species which have a wider distribution and extend into the tropical and northern extra-tropical regions. The number of such species is 68 (or 27 per cent. of the total number[1] of species found at these twenty-nine Stations), and for the purposes of this discussion they may be divided into groups in accordance with their distribution. Thus we find that of these 68 species,

25 species (or 37 per cent.) are known to occur in regions within the tropics, but not north of the tropical zone (List II*c*.);

19 species (or 28 per cent.) are known to occur to the north of the tropics, but not within the intervening tropical zone (List II*d*.); and

24 species (or 35 per cent.) are known to occur both within and to the north of the tropics, some of which may for the present be regarded as almost cosmopolitan (List II*e*.).

We may now proceed to consider in detail the distribution of these 68 species according to the groups given above, indicating briefly the geographical and bathymetrical distribution of each species northward of the tropic of Capricorn.

LIST II *c*.

In the first place we give a list of the 25 species which extend within the tropics, but are unknown up to the present time to the north of the tropic of Cancer. From the

[1] Not including the 48 species occurring also in the deep-water area of the Kerguelen Region (see footnote, p. 36).

distributional notes accompanying each species it will be observed that 15 of the species are true deep-sea forms, being unknown from depths less than 1000 fathoms; the other 10 species, though found in depths greater than 1000 fathoms in the regions represented by these twenty-nine Stations, occur outside those regions in depths less than 1000 fathoms, and only one of these species (*Cythere scutigera*) appears to be an inhabitant of shallow water under 150 fathoms. It will also be noticed that 15 of the species occur in the tropical Pacific, 7 species in the tropical Atlantic, while 1 species is common to both the tropical Pacific and tropical Atlantic, the remaining 2 species being recorded from the Indian Ocean.

Esperella biserialis—Tropical Pacific, 2385 fathoms.
Solenosmilia variabilis—Tropical Atlantic, 420 fathoms; also near Marion Island, 310 fathoms.
Freyella benthophila—Tropical Indian Ocean, 1520 to 1997 fathoms.
Marsipaster hirsutus—Tropical Indian Ocean, 1997 fathoms.
Ophioglypha ornata—Tropical Pacific, 2000 fathoms.
Ophiomastus tegulitius—Tropical Pacific, 1070 fms.; also near Australia and New Zealand, 410 and 275 fms.
Aspidodiadema microtuberculatum—Tropical Atlantic, 350 and 1600 fathoms.
Cystechinus clypeatus—Tropical Pacific, 1050 fathoms.
Benthodytes papillifera—Tropical Pacific, 1400 and 2425 fathoms.
Psychropotes semperiana—Tropical Atlantic, 2500 fathoms.
Buskiella abyssorum—Tropical Atlantic, 1850 and 2500 fathoms.
Cythere scutigera—Tropical Pacific, 15 to 37 fathoms; also near New Zealand, 150 fathoms.
Stenopleura atlantica—Tropical Atlantic, 1850 fathoms.
Acanthephyra longidens—Tropical Pacific, 2150 fathoms.
Benthesicymus brasiliensis—Tropical Pacific, 315, 1400, and 2440 fathoms.
Haliporus curvirostris—Tropical Pacific, 2385 fathoms.
Hemipenœus spinidorsalis—Tropical Pacific, 2050 fathoms.
Pentacheles lævis—Tropical Pacific, 500 fathoms.
Pontophilus gracilis—Tropical Pacific, 1400 and 2150 fathoms.
Arca (*Barbatia*) *corpulenta*—Tropical Pacific, 200, 1400, 2000, and 2425 fathoms.
Bicellaria navicularis—Tropical Atlantic, 32 to 400 fathoms.
Flustra biseriata—Tropical Pacific, 825 fathoms.
Kinetoskias pocillum—Tropical Atlantic, 32 to 400 fathoms.
Octacnemus bythius—Tropical Pacific, 1070 fathoms.
Ipnops murrayi—Tropical Atlantic and tropical Pacific, 1600 and 2150 fathoms.

LIST II *d*.

In the second place we give a list of the 19 species which have been recorded from regions north of the northern tropic as well as south of the southern tropic, but which, up to the present time, are not known to occur within the intervening tropical zone. From the distributional notes accompanying each species it will be observed that 12 of the species are true deep-sea forms, being unknown from depths less than 1000 fathoms [in the case of *Pyrosoma spinosum*, though the trawl descended to a depth of 2200 fathoms, it is pretty certain the specimen entered the net near the surface]; the other 6 species, though found in depths greater than 1000 fathoms in the regions represented by these twenty-nine Stations, occur outside those regions in depths

less than 1000 fathoms, and only one of these species (*Pseudocythere caudata*) appears to be an inhabitant of shallow water under 150 fathoms. It will also be noticed that 16 of the species are represented in the North Atlantic and 4 species in the North Pacific, while only one of these 19 species (*Dentalium keras*) is common to both the North Atlantic and North Pacific.

Dytaster exilis—North Atlantic, 1700 fathoms.
Ophioglypha bullata—North Atlantic, 1240, 2075, 2650, and 2850 fathoms.
„ *irrorata*—North Atlantic, 470 to 1125 fathoms.
Phormosoma hoplacantha—North Pacific, 565 fathoms; also near S.E. Australia, 410 fathoms.
Euphronides depressa—North Atlantic, 1090 fathoms.
Eupista darwini—North Atlantic, 2750 fathoms.
Placostegus ornatus—North Pacific, 2900 and 3125 fathoms.
Cythere irpex—North Atlantic, 1000 fathoms.
Krithe tumida—North Atlantic, 2700 fathoms.
Pseudocythere caudata—North Atlantic, shallow; also near Marion and Kerguelen Islands, 20 to 150 fms.
Xestoleberis expansa—North Atlantic, 2700 fathoms.
Scalpellum velutinum—North Atlantic, 900 fathoms.
Neotanais americanus—North Atlantic, 1240 fathoms.
Glyphocrangon rimapes—North Pacific, 1875 fathoms.
Glomus nitens—North Atlantic, 500 to 1750 fathoms.
Dentalium keras—North Pacific, 2050 fathoms; Gulf of Mexico, 1568 fathoms.
Ianthina rotundata—North Atlantic, surface and 1000 fathoms.
Kinetoskias cyathus—North Atlantic, 1525 fathoms.
Pyrosoma spinosum—North Atlantic, 2200 fathoms (surface ?).

LIST II *e*.

In the third place we give a list of the 24 widely-distributed species which are known to occur both in the tropical and northern extra-tropical regions as well as south of the tropics. From the distributional notes accompanying each species, it will be observed that only 4 of the species are true deep-sea forms, being known only from depths greater than 1000 fathoms; the other 20 species, though found in depths over 1000 fathoms in the regions represented by these twenty-nine Stations, occur outside those regions in depths less than 1000 fathoms, and 8 of these species appear to be inhabitants of shallow water under 150 fathoms. Three of the species (viz., *Gennadas parvus*, *Parapagurus abyssorum*, and *Discina atlantica*) appear to be almost cosmopolitan.

Phakellia ventilabrum—Tropical Atlantic, 400 fathoms; North Atlantic and Arctic, over 100 fathoms.
Deltocyathus italicus—Tropical and North Atlantic and tropical Pacific, 200 to 1075 fathoms.
Rhizocrinus lofotensis—Tropical and North Atlantic, 80 to 955 fathoms.
Ophiomusium armigerum—Tropical and North Atlantic, 1650 and 1850 fathoms.
„ *lymani*—North Atlantic, tropical and North Pacific, 565 to 1250 fathoms; also near New Zealand, 700 fathoms.
Aceste bellidifera—North Atlantic and tropical Pacific, 620 and 2600 fathoms.
Brissopsis luzonica—Tropical and North Pacific, shore to 800 fathoms.
Echinus elegans—North Atlantic and tropical Pacific, 80 to 1350 fathoms.

Pourtalesia laguncula—Tropical and North Pacific, 345 to 2900 fathoms; also near New Zealand, 700 fathoms.

Salenia hastigera—Tropical and North Atlantic and tropical Pacific, 100 to 1850 fathoms; also near Kermadecs, 600 and 630 fathoms.

Holothuria murrayi—North Atlantic and tropical Pacific, 150 and 1090 fathoms.

Myriochele heeri—Tropical and North Atlantic, 1340 and 2975 fathoms.

Bairdia victrix—Tropical and North Atlantic, shallow water to 675 fathoms; also near Kerguelen and South-East Australia, 38 to 410 fathoms.

Cythere serratula—Tropical and North Atlantic, 390 and 1125 fathoms.

Xestoleberis curta—Tropical and North Atlantic, and tropical Pacific, 6 to 435 fathoms; also near Kerguelen and Port Jackson, 2 to 28 fathoms.

Acanthephyra brachytelsonis—Tropical and North Pacific, 200 to 775 fathoms; also near Kermadecs, 520 to 630 fathoms.

„ *sica*—North Atlantic, tropical and North Pacific, 200 to 2675 fathoms; also near Kermadecs and New Zealand, 520 and 700 fathoms.

Aristeus armatus—Tropical and North Pacific, 1400 to 2350 fathoms; tropical Indian Ocean, 1748 fathoms.

Benthesicymus altus—Tropical and North Pacific, 345 to 1400 fathoms; also near Kermadecs, 520 and 600 fathoms.

Gennadas intermedius—Tropical and North Atlantic, surface and 1850 fathoms.

„ *parvus*—Tropical and North Atlantic, tropical and North Pacific, surface (?) to 2500 fathoms; tropical Indian Ocean, 738 to 1644 fathoms.

Willemœsia leptodactyla—North Atlantic, 1900 fathoms; Mediterranean, 3000 m. (=1600 fathoms).

Parapagurus abyssorum—Tropical and North Atlantic, tropical and North Pacific, 1050 to 2175 fathoms; also Magellan Strait, 45 fathoms (?).

Discina atlantica—Tropical and North Atlantic, tropical and North Pacific, and Arctic, 200 to 2425 fathoms.

We may now summarise the distribution of these 68 species which extend into the tropical and northern extra-tropical regions, as follows:—

Bathymetrical Distribution.—It appears that of these 68 species, 31 species are known to occur only in depths greater than 1000 fathoms, while 37 species are recorded from both above and below the 1000 fathoms line (of which 12 species extend into shallow water under 150 fathoms; to these 12 species we must add 8 of the species confined to the Southern Hemisphere which have been recorded from shallow water under 150 fathoms).

LIST II *f*.

We give here the names of the 20 species which extend from deep water over 1000 fathoms into shallow water under 150 fathoms, of which 3 species (viz., *Brissopsis luzonica*, *Phascolosoma catharinæ*, and *Venus* (*Chamelæa*) *mesodesma*) have been recorded from the shore:—

(?) *Phakellia ventilabrum.*
Rhizocrinus lofotensis.
Brissopsis luzonica.
Echinus elegans.
(?) *Salenia hastigera.*
Cerebratulus angusticeps.
Phascolosoma catharinæ.
Argillœcia eburnea.
Bairdia victrix.
Cythere scutigera.
„ *stolonifera.*
(?) *Cytheropteron fenestratum.*
Pseudocythere caudata.
Xestoleberis curta.
Elasmopus subcarinata.
(?) *Parapagurus abyssorum.*
Venus (*Chamelæa*) *mesodesma.*
(?) *Bicellaria navicularis.*
(?) *Kinetoskias pocillum.*
Magasella flexuosa.

Six of the above species are preceded by a mark of interrogation:—*Phakellia ventilabrum*, *Salenia hastigera*, and *Cytheropteron fenestratum* have been recorded only from depths over 100 fathoms, and might, therefore, not merit the title of shallow-water species; *Parapagurus abyssorum* is said to have been dredged from a depth of 45 fathoms in Magellan Strait, but the author of the Challenger Report on the Anomura regards this as an error, as he thinks a shallow-water habitat for the species is quite out of the question; the two species of Polyzoa (*Bicellaria naviculoris* and *Kinetoskias pocillum*) are recorded from the coast of Brazil, "32 to 400 fathoms," so that it is doubtful whether they actually came from less than 150 fathoms.

Geographical Distribution.—Of the 68 species we find that:—

35	species	are	represented	in the North Atlantic area,
32	,,	,,	,,	Tropical Pacific area,
21	,,	,,	,,	Tropical Atlantic area,
14	,,	,,	,,	North Pacific area,
4	,,	,,	,,	Tropical Indian Ocean,
2	,,	,,	,,	Arctic Ocean.

LIST II *g*.

In List II. those species apparently limited to the Southern Hemisphere south of the tropic of Capricorn are distinguished by an asterisk. A few of these species were, however, obtained in depths less than 1000 fathoms in the Southern Hemisphere, as well as in depths over 1000 fathoms among the twenty-nine Stations under consideration. We give here a list of 16 such species, with an indication of the localities in which each species occurred in depths less than 1000 fathoms.

Ophiactis poa—Near Tristan da Cunha, 500 fathoms.
Ophioglypha jejuna—Near Tristan and Sydney, 500 and 410 fathoms.
,, *meridionalis*—Near River Plate, 600 fathoms.
Ophiozona stellata—Near New Zealand, 700 fathoms.
Cerebratulus angusticeps—Near New Zealand, 10 fathoms.
Phascolosoma catharinæ—Brazil, shore.
Eunoa opalina—Magellan Strait, 245 fathoms [specimen from deep water is an eyeless variety].
Argillœcia eburnea—Kerguelen, 20 to 120 fathoms.
Cythere normani—Near Heard Island, 150 fathoms.
,, *stolonifera*—Cape, 15 to 20 fathoms.
Cytheropteron fenestratum—Kerguelen, 120 fathoms.
Elasmopus subcarinata—Bass Strait, Port Jackson, New Zealand, 30 to 50 fathoms.
Acanthomunna proteus—Near New Zealand, 700 fathoms.
Serolis neœra—Near River Plate, 600 fathoms.
Venus (*Chamelœa*) *mesodesma*—New Zealand, shore [the localities Valparaiso and Philippines, assigned to this species, require verification].
Magasella flexuosa—Falklands and Patagonia, 5 to 12 fathoms.

As already stated, of the twenty-nine Stations where the Challenger dredged in depths of over 1000 fathoms to the south of the tropic of Capricorn (excluding the eight deep-water Stations in the Kerguelen Region), fifteen Stations are situated in the South Atlantic, between lat. 24° 38′ and 48° 37′ S., and fourteen Stations in the South Pacific, between lat. 32° 36′ and 42° 43′ S.

Of the 253 species and varieties of marine Metazoa obtained at these Stations,[1]

101 species (or 40 per cent.) were taken only in the South Atlantic,
140 „ („ 55 „) „ „ „ South Pacific, and
12 „ („ 5 „) „ „ both in the S. Atlantic and S. Pacific.

For convenience of reference it is desirable to indicate the species taken in each of these oceanic regions.

LIST II *h*.

In the first place we give a list of the 101 species taken only in the South Atlantic deep-water Stations :—

Psammina plakina.
Cladorhiza inversa.
Phakellia ventilabrum.
Caulocalyx tener.
Holascus stellatus.
Hyalonema tenue.
„ sp. (?).
Anthoptilum simplex.
Schizopathes crassa.
Solenosmilia variabilis.
Nauphanta challengeri.
Anthemodes articulata.
Bathyphysa gigantea.
Rhizocrinus lofotensis.
Dytaster exilis, var. *gracilis.*
„ *nobilis.*
Hymenaster anomalus.
„ *pergamentaceus.*
Pontaster pristinus.
Porcellanaster eremicus.
Pythonaster murrayi.
Amphiura dalea.
Ophiactis poa.
Ophiocten umbraticum.
Ophioglypha bullata.
„ *irrorata.*
„ *jejuna.*
„ *meridionalis.*
Ophiomusium archaster.
Ophiomyces grandis.
Ophiophyllum sp. (?).
Aceste bellidifera.
Cystechinus clypeatus.
Echinus elegans.
Salenia hastigera.
Psychropotes semperiana.
Scotoplanes albida.
„ *papillosa.*
Phascolosoma catharinæ
Amphicteis sarsi.
Buskiella abyssorum
Eupista grubei.
Myriochele heeri.
Argillœcia eburnea.
Bairdia victrix.
Bythocypris elongata.
Cythere dorsoserrata.
„ *irpex.*
„ (?) *serratula*
„ *squalidentata*
Cytheropteron fenestratum.
Krithe tumida.
Pseudocythere caudata.
Xestoleberis expansa.
Scalpellum carinatum.
„ *eximium.*
„ *velutinum.*
Verruca gibbosa.

[1] Not including the 48 species occurring also in the deep-water area of the Kerguelen Region (see footnote, p. 36).

Verruca incerta.
„ *quadrangularis.*
Lanceola sp. (?).
Œdiceroides cinderella.
Orchomene abyssorum.
Stenopleura atlantica.
Neotanais americanus.
Serolis neœra.
Acanthephyra brachytelsonis.
Aristeus armatus.
Benthesicymus altus.
„ *iridescens.*
„ *mollis.*
Gennadas intermedius.
Hemipenœus speciosus.
„ *spinidorsalis.*
Notostomus murrayi.
Colossendeis brevipes.
Cryptodon moseleyi.
Glomus nitens.
Lima (*Limatula*) sp. (?).
Lyonsiella grandis.
Malletia pallida.
Venus (*Chamelœa*) *mesodesma.*
Basilissa simplex.
Clathurella cala.
Dentalium amphialum.
Ianthina rotundata.
Pleurotoma (*Spirotropis*) *aganactica.*
Stilifer brychius.
Trochus sp. (?).
Histiopsis atlantica.
Bicellaria navicularis.
Bugula margaritifera.
Cellularia crateriformis.
Farciminaria cribraria.
„ *magna.*
Kinetoskias cyathus.
Pyrosoma spinosum.
Bathylagus atlanticus.
Bathypterois longipes.
Ipnops murrayi.
Macrurus affinis.

LIST II *i*.

In the second place we give a list of the 140 species taken only in the South Pacific deep-water Stations :—

Holopsamma argillaceum.
Axoniderma mirabile.
Esperella biserialis.
Tedania actiniiformis.
Trichostemma irregularis.
Thenea wrightii.
„ sp. (?).
Bathydorus baculifer.
Hyalonema poculum.
„ (*Stylocalyx*) *tenerum.*
Hyalostylus dives.
Trachycaulus gurlittii.
Dictyonine undetermined.
Aulorchis paradoxa.
Corallimorphus profundus.
Edwardsia sp. (?).
Epizoanthus thalamophilus.
Ophiodiscus annulatus.
„ *sulcatus.*
Palythoa (?) sp.
Paractis excavata.
Phellia (?) sp.
Polyopis striata.
Polystomidium patens.
Actinian undetermined.
Deltocyathus italicus.
Leptopenus hypocœlus.
Leonura terminalis.
Periphylla mirabilis.
Tesserantha connectens.
Dytaster exilis.
Freyella benthophila.
Hymenaster carnosus.
„ *echinulatus.*
„ *geometricus.*
„ *porosissimus.*
„ *vicarius.*
Hyphalaster diadematus.
Marsipaster hirsutus.
„ *spinosissimus.*
Porcellanaster crassus.
„ *gracilis.*
Amphilepis patens.
Ophiacantha sentosa.
Ophioglypha ornata.
„ sp. (?).

Ophiomastus tegulitius.
Ophiothamnus sp. (?).
Ophiotholia supplicans.
Ophiozona stellata.
Brissopsis luzonica.
Phormosoma asterias.
„ *hoplacantha.*
Pourtalesia laguncula.
Benthodytes abyssicola.
„ *mamillifera.*
„ *papillifera.*
„ *sanguinolenta.*
Cucumaria abyssorum, var. *grandis.*
Elpidia verrucosa.
Enypniastes eximia.
Euphronides depressa.
Holothuria murrayi.
Pœlopatides confundens.
Parelpidia cylindrica.
„ *elongata.*
Peniagone vitrea.
Stichopus (?) *torvus.*
Trochostoma sp. (?).
Two Holothurians undetermined.
Cerebratulus angusticeps.
Eumenia reticulata.
Eunoa opalina.
Eupista darwini.
Euthelepus chilensis.
Leœna langerhansi.
„ *neo-zealaniœ.*
Lumbriconereis abyssorum.
Maldanella neo-zealaniœ.
„ *valparaisiensis.*
Melinna armandi.
Nothria ehlersi.
„ *pycnobranchiata.*
Placostegus mörchii.
„ *ornatus.*
Samythopsis grubei.
Vermilia (?) sp.
Bairdia hirsuta.
Crossophorus imperator.
Cythere normani.
„ *scutigera.*
„ *stolonifera.*
„ *sulcatoperforata.*
Xestoleberis curta.
Scalpellum darwinii.
„ *minutum.*
Andania abyssorum.
Camacho bathyplous.
Elasmopus subcarinata.
Gammaropsis thomsoni.
Lanceola sp. (?).
Leucothoë tridens.
Podocerus hoeki [= *tuberculatus*].
Acanthocope acutispina.
Acanthomunna proteus.
Eurycope novœ-zelandiœ.
Ischnosoma bacilloides.
Munnopsis gracilis.
Serolis sp. (?).
Acanthephyra longidens.
Gennadas parvus.
Haliporus curvirostris.
Hepomadus inermis.
Pentacheles lœvis.
Pontophilus profundus.
Elasmonotus marginatus.
Galacantha bellis.
Tylaspis anomala.
Colossendeis media.
Nymphon compactum.
„ *longicollum.*
„ *longicoxa.*
„ *procerum.*
Arca (*Barbatia*) *corpulenta.*
Dentalium keras.
Nassa dissimilis.
Pleurotoma (*Thesbia*) *membranacea.*
„ („) *xanthias.*
Flustra biseriata.
Kinetoskias pocillum.
Menipea pateriformis.
Discina atlantica.
Magasella flexuosa.
Waldheimia wyvillii.
Octacnemus bythius.
Bathypterois longicauda.
Bathysaurus ferox.
Macrurus fernandezianus.
„ *murrayi.*

LIST II *k*.

In the third place we give a list of the 12 species taken both in the South Atlantic and South Pacific deep-water Stations :—

Ophiomusium armigerum.
„ *lymani.*
Aspidodiadema microtuberculatum.
Cyphocaris micronyx.
Acanthephyra sica.
Benthesicymus brasiliensis.
Glyphocrangon rimapes.
Pontophilus gracilis.
Sergestes profundus.
Willemœsia leptodactyla.
Parapagurus abyssorum.
Chlorophthalmus gracilis.

To these 12 species must be added *Dytaster exilis*, the type form of which was taken in the South Pacific and the variety *gracilis* in the South Atlantic.

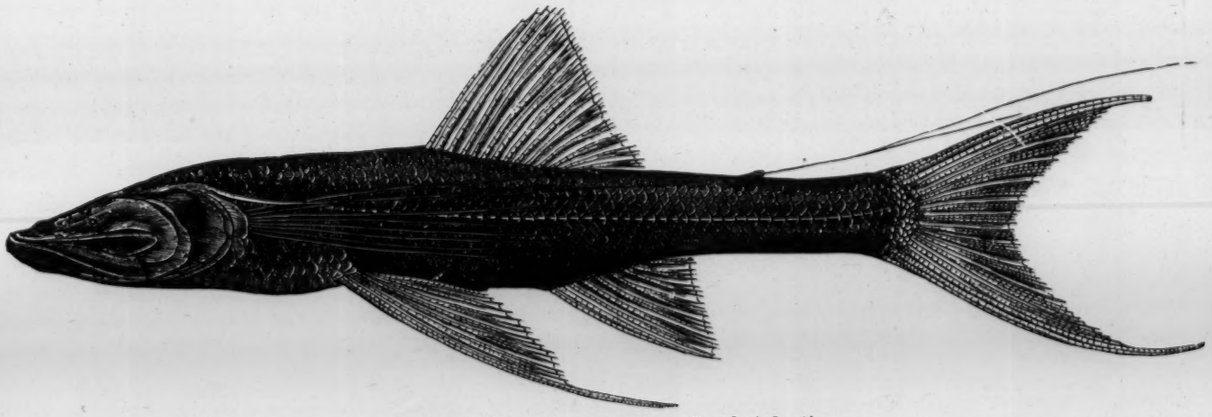
Turning now our attention to the genera represented at these twenty-nine Stations in the Southern Hemisphere, we find that out of the total number (182) 19 genera (or 10 per cent.) are known up to the present time only from these Stations.

LIST III.

We give here a list of these 19 genera, the great majority of which include only a single species taken each at a single Station, but two of the genera (*Ophiodiscus* and *Parelpidia*) each contain 2 species, each species being represented at a distinct Station.

Axoniderma.
Caulocalyx.
Hyalostylus.
Trachycaulus.
Aulorchis.
Ophiodiscus.
Polyopis.
Polystomidium.
Nauphanta.
Tesserantha.
Pythonaster.
Ophiotholia.
Enypniastes.
Parelpidia.
Samythopsis.
Crossophorus.
Camacho.
Tylaspis.
Histiopsis.

To these 19 genera may be added the genus *Acanthomunna* with a single species, which was taken at two neighbouring Stations near New Zealand, one of them being, however, under 1000 fathoms (viz., Stations 168 and 169, 1100 and 700 fathoms).



Bathypterois longipes, Günther. South Atlantic.

Total Number of Species of Marine Metazoa procured by the Challenger in the Southern Hemisphere South of the Tropics, in Depths exceeding 1000 Fathoms.

If now we combine the information in the two preceding lists (Lists I. and II.) of species taken by the Challenger in the two groups of deep-water Stations to the south of the southern tropic, we shall have a fair general idea of the deep-sea Metazoan fauna of the Southern Hemisphere in depths over 1000 fathoms so far as at present known.

There are in all thirty-seven Stations, at twenty-nine of which the trawl was used, and the dredge was sent down at the remaining eight Stations.

15 of the Stations are situated in the South Atlantic or its extension into the Southern Ocean,
14 „ „ South Pacific or its extension into the Southern Ocean, and
8 „ „ Southern Indian Ocean (Kerguelen Region).

The total number of species obtained is 523, belonging to about 312 genera, the proportion of genera to species being as 1 to 1·67.

272 species (or 52 per cent. of the total number) occur in the Kerguelen Region,
194 „ („ 37 „ „ „) occur in the South Pacific, and
138 „ („ 26 „ „ „) occur in the South Atlantic.

These figures show that in the eight deep-water Stations of the Kerguelen Region, a much larger number of species was procured than at nearly double the number of Stations, situated, however, nearer the tropics, in the South Atlantic or in the South Pacific.

Of the 523 species obtained we find that

164 species (or 31 per cent. of the total number) are known only from the Kerguelen Region,
89 „ („ 17 „ „ „) are known only from the South Pacific, and
54 „ („ 10 „ „ „) are known only from the South Atlantic.

There are, in addition, 29 species (or 6 per cent. of the total number) which, though not confined to any one of these three divisions, are known only from these deep-water Stations of the Southern Hemisphere south of the tropic of Capricorn ; of these 29 species,

20 species are common to the Southern Indian and South Pacific areas,
5 „ „ „ „ South Atlantic areas,
3 „ „ South Atlantic and South Pacific areas,
1 „ „ to all three divisions (South Indian, South Atlantic, and South Pacific).

Of the 523 species present in these deep-water Stations of the Southern Hemisphere there are thus altogether 336 species (or 64 per cent.) which, so far as our knowledge at present extends, are unknown outside the area represented by these deep-water Stations.

Besides these 336 species known only from deep water in the Southern Hemisphere south of the southern tropic, there are 28 species (or 5 per cent. of the total number present) not known to occur to the northwards of the southern tropic, but occurring in shallower water less than 1000 fathoms in southern regions.

There are 121 species (or 23 per cent. of the total number) which extend to regions north of the tropic of Capricorn, and their distribution outside this area may be shown thus :—

43 species (8 per cent.) occur to the *north* of the tropics (but not within the tropics),
41 „ (8 „) „ both *within* and *north* of the tropics,
37 „ (7 „) „ *within* the tropics (but not north of the tropics).

These 121 species are represented in the various oceanic regions as follows :—

62	species	(or 12	per cent.)	occur	in the	North Atlantic,
49	„	(„ 9	„)	„		Tropical Pacific,
37	„	(„ 7	„)	„		Tropical Atlantic,
36	„	(„ 7	„)	„		North Pacific,
7	„	(„ 1	„)	„		Indian Ocean,
4	„	(„ 1	„)	„		Arctic Ocean.

As regards the bathymetrical distribution of the species taken at these deep-water Stations of the Southern Hemisphere, 336 species, as already stated, are known only from these Stations, and are consequently known only from depths over 1000 fathoms. Of the species with a wider distribution, 54 species are known only from deep water over 1000 fathoms, making a total number of 390 exclusively deep-sea species (or 74 per cent. of the total number present). The remaining 93 species occur both in deep water over 1000 fathoms and in lesser depths, of which 39 species have been recorded from shallow water under 150 fathoms, 4 of which are known from the shore. The depth at which 2 species occur outside the area under consideration is not recorded.

Of the 312 genera represented at these deep-water Stations, 57 genera (or 18 per cent.) are known only from these Stations, and there are, besides, 3 genera which are known, apart from these Stations, only from shallower water south of the southern tropic.

LIST III.

METAZOA PROCURED BY THE CHALLENGER IN INTERMEDIATE DEPTHS BETWEEN 150 AND 1000 FATHOMS, IN THE KERGUELEN REGION.

Returning now to the region in the Southern Indian Ocean traversed by the Challenger during the cruise from the Cape of Good Hope to Australia, which is the special subject of this paper, we proceed to complete our review of the marine fauna of this Kerguelen Region by giving a list of the species taken by the Challenger in depths less than 1000 fathoms. We give in the first place a list of the species taken in moderate depths (between 1000 and 150 fathoms), reserving for a future list (List IV.) the essentially shallow-water species taken in depths less than 150 fathoms in the same region. There were only three dredgings taken in intermediate depths between 150 and 1000 fathoms, viz., at Station 145a, near Marion Island, in 310 fathoms, and at Stations 148 and 148a, near the Crozet Islands, in 210 and 550 fathoms; the trawl was not used at any of these Stations. The species known only from these dredgings are indicated by an asterisk *.

MONAXONIDA:

Axinella erecta (Carter).
**Esperiopsis symmetrica*,[1] Ridley and Dendy.
Gellius carduus,[2] Ridley and Dendy.
Iophon chelifer,[3] Ridley and Dendy.
* ,, *laminalis*,[4] Ridley and Dendy.

[1] *Esperiopsis symmetrica* is a very remarkable sponge, the most noticeable feature in which is the radiately symmetrical arrangement of the skeleton.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 78.)

[2] *Gellius carduus* is readily distinguished by its very characteristic external form, the surface resembling that of a large thistle-leaf, whence the specific name. The shape of the skeleton spicules is also very characteristic. . . . The variety *magellanica* is a very interesting geographical variety from the Strait of Magellan. The main features in which it differs from the type specimens concern the oxeote spicules which, in the variety in question, are much more pointed and a good deal shorter than in the type.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 39, 40.)

[3] Three specimens of this interesting species [*Iophon chelifer*] are present; two are fairly large, but broken into fragments, the other is small, and occurs encrusting a branched Polyzoon. The latter is in all probability a young form, and differs in several minor respects from the larger specimens. . . . The species differs very decidedly from all described forms in the large size and also in the degree of elaboration of the bipocillate spicules. The other spicules are also larger in almost every case than the corresponding forms in other species of *Iophon; Iophon* (*Alebion*) *piceum*, Vosmaer, from Barents Sea, approaches it the most nearly in this respect.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 119–120.)

[4] Only one specimen, broken into fragments, of this interesting species [*Iophon laminalis*] was obtained. In the fine state of development of its bipocillate microsclera it approaches *Iophon chelifer*, a specimen of which was obtained at the same Station; while in external form it probably comes near *Iophon piceum*, Vosmaer, from Barents Sea. The species to which it is perhaps most nearly related is, however, *Iophon cylindricus* (from off Cape Howe), which, like it, has the stylote spicule smooth.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 121.)

Myxilla nobilis,[1] Ridley and Dendy.
**Phakellia papyracea*,[2] Ridley and Dendy.
**Suberites mollis*,[3] Ridley and Dendy.

[TETRACTINELLIDA :

Tetilla antarctica (Carter). Taken by Ross' Antarctic Expedition in the neighbourhood of Victoria Land (lat. 74° 30′ and 77° 30′ S.), 206 and 300 fathoms.]

HEXACTINELLIDA :

**Acanthascus grossularia*, Schulze.
**Aulascus johnstoni*, Schulze.
Aulocalyx irregularis, Schulze.
Chonelasma lamella, Schulze.
,, sp. (?).

ALCYONARIA :

**Acanthogorgia ramosissima*, Wright and Studer.
**Lophogorgia lutkeni*, Wright and Studer.
Pleurocorallium secundum, Dana.
**Primnoides sertularoides*, Wright and Studer.
Primnoisis antarctica (Studer).
**Stenella spinosa*, Wright and Studer.
Thouarella antarctica (Valenciennes).
,, *variabilis*,[4] Wright and Studer.
,, ,, var. *brevispinosa*, Wright and Studer.

[1] The species which we have called *Myxilla nobilis*, and its varieties, have given us a great deal of trouble in determining their true relations ; they appear to be sufficiently connected *inter se* to warrant us in considering them all as varieties of one species, and that species perhaps finds its nearest already known ally in BOWERBANK'S *Hymeniacidon* (*Myxilla*) *paupertas* [British] ; the two species seem, however, to be distinct.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 143.)

[2] *Phakellia papyracea* is a very delicate species, which perhaps comes near to BOWERBANK'S *Isodictya infundibuliformis* [British], more especially if it should ultimately prove to be cup-shaped when perfect, but it is distinguished at once and absolutely from that species by the absence of the oxeote spicules, so that further comparisons are needless. In the absence of the oxeote spicules, however, it agrees with VON MARENZELLER'S *Cribrochalina ambigua* [from Jan Mayen], but differs widely in the size of the spicules, while there do not seem to be two distinct sizes as in our sponge. —(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 172.)

[3] The most remarkable features of this sponge [*Suberites mollis*] are its great softness and looseness of texture, as compared with the more typical species of *Suberites*, and the reduction of the "dermal crust" of spicules, which no longer forms a distinct cortical layer.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 205.)

[4] *Thouarella variabilis*, of which there are numerous examples, varies to an extraordinary degree in the size of the calyces, the development of the spines, and the development of the colony, without it being possible thereby to sharply separate the individual forms specifically. Nevertheless one can generally distinguish the following three varieties from each other : *a*. the type (Station 145, 310 fathoms), *b*. var. *brevispinosa* (Station 145, 310 fathoms), *c*. var. *gracilis* (Station 150, 150 fathoms).—(WRIGHT and STUDER, *Zool. Chall. Exp.*, part 64, p. 68.)

ANTIPATHARIA :

**Cladopathes plumosa*, Brook.
**Schizopathes conferta*, Brook.

CORALS :

Flabellum apertum, Moseley.
Solenosmilia variabilis, Duncan.

ASTEROIDEA :

Cribrella præstans, Sladen.
,, *simplex*, Sladen.
**Leptoptychaster antarcticus*,[1] Sladen.

OPHIUROIDEA :

Amphiura studeri, Lyman.
Astrotoma agassizii, Lyman.
Ophiacantha rosea, Lyman.
**Ophioglypha elevata*, Lyman.
Ophiolebes scorteus, Lyman.

ECHINOIDEA :

Echinus magellanicus, Phil.

HOLOTHURIOIDEA :

Cucumaria serrata, Théel, var. *marionensis*, Théel.
Psolus ephippifer, Wyville Thomson.
**Stichopus challengeri*, Théel.

ANNELIDA :

Lagisca magellanica, M'Intosh, var. *grubei*, M'Intosh.
Polyeunoa lævis, M'Intosh.

AMPHIPODA :

**Atylopsis emarginatus*, Stebbing.

ISOPODA :

Arcturides cornutus, Studer.
Serolis latifrons, White.

[1] This form [*Leptoptychaster antarcticus*] is unquestionably the southern representative of *Leptoptychaster arcticus* (Sars) of the North Atlantic, to which it is structurally nearly related. . . . It is interesting to note that *Leptoptychaster antarcticus* is more nearly related to the distant Arctic form than to the comparatively neighbouring species *Leptoptychaster kerguelenensis*; perhaps a more extended series of specimens than we possess at present might lead to *Leptoptychaster antarcticus* being ranked as a variety only of the northern form. At present I do not feel justified in taking that step.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 192.)

MACRURA :

**Chorismus tuberculatus*, Bate.

ANOMURA :

**Lithodes murrayi*,[1] Henderson.
Munida spinosa, Henderson.
**Paralomis aculeatus*, Henderson.
**Uroptychus insignis*, Henderson.

LAMELLIBRANCHIATA :

**Neæra fragilissima*,[2] Smith.

GASTEROPODA :

**Jeffreysia edwardiensis*, Watson.
Puncturella noachina[3] (Linné), var. *princeps*, Mighels.

POLYPLACOPHORA :

**Lepidopleurus dorsuosus*, Haddon.

POLYZOA :

Caberea darwinii, Busk.
Cellepora mamillata, var. *atlantica*, Busk.
,, *vagans*, Busk.
Escharoides occlusa, Busk.
Farciminaria hexagona, Busk.
Mucronella ventricosa, var. *multispinata*, Busk.
Myriozoum marionense, Busk.
Nellia oculata, Busk.
**Retepora cavernosa*, Busk.
* ,, *gigantea*, Busk.
**Reteporella myriozoides*, Busk.
Schizoporella elegans (d'Orbigny).
**Smittia graciosa*, Busk.

BRACHIOPODA :

**Terebratula moseleyi*, Davidson.

[1] *Lithodes murrayi* is apparently most closely allied to *Lithodes maia* [from the North Atlantic], but the latter species is of large size, and the spines on the carapace are more numerous and more uniformly equal in size.—(HENDERSON, *Zool. Chall. Exp.*, part 69, p. 44.)

[2] *Neæra fragilissima* is a large and very fragile species, in many respects similar to *Neæra curta*, Jeffreys [from the North Atlantic].—(SMITH, *Zool. Chall. Exp.*, part 35, p. 54.)

[3] After careful study I have found it impossible to separate the southern form from the species of LINNÉ [*Puncturella noachina*—a northern species].—(WATSON, *Zool. Chall. Exp.*, part 42, p. 43.)

FISHES :

**Lepidopsetta maculata*, Günther.
**Macrurus carinatus*, Günther.

As in the case of the preceding lists, the majority of the 68 species were taken only at one Station, in fact only four species (viz., *Axinella erecta*, *Iophon chelifer*, *Phakellia papyracea*, and *Cribrella simplex*) were found to be common to both the Marion Island and Crozet Islands localities.

The preceding list shows that in the vicinity of Marion and the Crozet Islands, in depths between 210 and 550 fathoms, the Challenger procured 68[1] species and varieties of Metazoa, belonging to 61 genera. The large proportion of genera relatively to the number of species is here very striking, for, except in five cases, each individual species is the representative of a distinct genus.

One of the species has received no specific name, and there is besides one variety enumerated as well as the species to which it belongs, so that there remain 66 distinct fully-described species the distribution of which may be discussed in detail.

These 66 species may be divided into those that are known only from the dredgings under consideration, and those that extend into other regions of the ocean.

a. *Species limited to the area under consideration.*

In the first place, we find that there are 30 species (or 44 per cent. of the total number) which, as far as we know, are confined to the region represented by these Stations. These 30 species are distinguished by an asterisk in the list, and we can say nothing about them beyond the fact that they are known only from this region and from depths between 210 and 550 fathoms; only one of the species (*Phakellia papyracea*) occurred both in the vicinity of Marion Island and of the Crozet Islands.

b. *Species extending outside the area under consideration.*

We come now to consider those species with a wider distribution which extend into other regions of the ocean outside the area represented by these three Stations. The number of such species is 36 (or 53 per cent. of the total number of species and varieties found at these three Stations), and they may be divided into groups according to their distribution in the tropical and extra-tropical regions of the ocean. Thus we find that of these 36 species,

21 species (or 58 per cent.) are known from other regions south of the southern tropic (see List III*a*.);

7 species (or 19 per cent.) are known from between the tropics, but not from regions north of the northern tropic (see List III*b*.);

[1] The species taken by Ross' Antarctic Expedition (*Tetilla antarctica*) is not included in these and succeeding remarks.

6 species (or 17 per cent.) are known from regions north of the tropic of Cancer, but not from the intervening tropical zone (see List III*c*.); and
2 species (or 6 per cent.) are known both from regions within and north of the tropics (see List III*d*.).

We may now consider in detail the distribution of these 36 species, according to the groups given above, indicating briefly the geographical and bathymetrical distribution of each species outside the region represented by these three Stations; five of the species (viz., *Axinella erecta*, *Aulocalyx irregularis*, *Solenosmilia variabilis*, *Ophiolebes scorteus*, and *Echinus magellanicus*) occur in the previous lists (Lists I. and II.) and the distributional notes need not be repeated here.

LIST III *a*.

In the first place we give a list of the 21 species which are known to occur outside the region under consideration only in somewhat similar latitudes, *i.e.*, in regions south of the tropic of Capricorn. From the distributional notes it will be observed that 2 of the species are known from deep water over 1000 fathoms (the distribution of which has already been discussed in detail); other 5 species are unknown in depths less than 150 fathoms; the remaining 14 species extend into shallow water under 150 fathoms.

Gellius carduus—Marion Island, 50 to 150 fathoms; Magellan Strait, 245 fathoms (var.).
Iophon chelifer—Near the Cape, 150 fathoms.
Myxilla nobilis—Magellan Strait, 140 and 245 fathoms (vars.); near River Plate, 600 fathoms.
Primnoisis antarctica—Kerguelen, shallow water.
Thouarella antarctica—Falkland Islands, shallow water.
„ *variabilis*—Near Heard Island, 150 fathoms (var).
Cribrella simplex—Kerguelen, 10 to 50 fathoms (var.); Tristan da Cunha, 90 to 150 fathoms.
Amphiura studeri—Marion Island, 50 to 150 fathoms; Kerguelen, 20 to 60 fathoms; Heard Island, 75 fathoms.
Astrotoma agassizii—Near Heard Island, 150 fathoms; Magellan Strait, 40 to 175 fathoms; between Magellan Strait and Falkland Islands, 55 fathoms.
Ophiolebes scorteus (for distribution, see List I.).
Echinus magellanicus (for distribution, see List I.).
Cucumaria serrata—Marion Island, 50 to 75 fathoms; Heard Island, 75 and 150 fathoms.
Psolus ephippifer—Marion Island, depth (?); Kerguelen, 20 to 60 fathoms; Heard Island, 75 and 150 fathoms.
Lagisca magellanica—Kerguelen, 127 fathoms; Magellan Strait, 175 and 400 fathoms.
Polyeunoa lævis—Magellan Strait, 400 fathoms.
Arcturides cornutus—Kerguelen, shallow water.
Serolis latifrons—Kerguelen, 5 to 40 fathoms; Auckland Islands, shallow water.
Munida spinosa—Near River Plate, 600 fathoms.
Mucronella ventricosa—Marion Island, 80 to 150 fathoms.
Myriozoum marionense—Marion Island, 50 to 150 fathoms; Heard Island, 75 fathoms.
Schizoporella elegans—Near the Cape, 150 fathoms.

LIST III *b*.

In the second place we give a list of the 7 species which extend into the tropics, but are not known to occur to the north of the northern tropic. From the distributional notes it will be observed that 2 of the species are known from deep water over 1000 fathoms (the distribution of one of which has already been noted); other 4 species extend into shallow water under 150 fathoms. Two of the species are unknown in depths less than 150 fathoms.

Solenosmilia variabilis (for distribution, see List II.).
Cribrella præstans—Indian Ocean, 240 to 480 fathoms.
Caberea darwinii—Marion Island, 50 to 150 fathoms; Kerguelen, 45 to 127 fathoms; near Cape, 150 fathoms; Tristan, 110 and 150 fathoms; Magellan Strait, New Zealand, and Cumberland Island, depth (?).
Cellepora mamillata—Bahia, 10 to 20 fathoms; Patagonia and Australia, depth (?).
„ *vagans*—Sandwich Islands, 20 to 40 fathoms.
Escharoides occlusa—Cape York, 8 fathoms; Philippines, 10 fathoms.
Farciminaria hexagona—Near Amboina, 825 and 1425 fathoms.

LIST III *c*.

In the third place we give a list of the 6 species which are known to occur north of the northern tropic, but which have not hitherto been recorded from the intervening tropical zone. From the distributional notes it will be observed that 4 of the species are known from deep water over 1000 fathoms (the distribution of two of which has already been discussed); 2 of the species extend into shallow water under 150 fathoms, being at the same time represented in deep water over 1000 fathoms, viz., *Axinella erecta* and *Puncturella noachina*, the remaining 3 species being unknown in depths less than 150 fathoms.

Axinella erecta (for distribution, see List I.).
Aulocalyx irregularis (for distribution, see List I.).
Chonelasma lamella—Near Kermadec Islands, 630 fathoms; North Atlantic near Bermuda, 1075 fathoms.
Flabellum apertum—North Atlantic, off coast of Portugal, 900 fathoms.
Ophiacantha rosea—Magellan Strait, 175 fathoms; near Japan, 420 to 775 fathoms.
Puncturella noachina—Marion Island, 69 and 140 fathoms; Kerguelen, 60 fathoms; Magellan Strait, 9 to 15 fathoms; Arctic, North Atlantic and North Pacific, 5 to 1095 fathoms.

LIST III *d*.

In the fourth place the following 2 species occur both in the tropical and northern extra-tropical regions; they are unknown in depths over 1000 fathoms, and extend into shallow water under 150 fathoms.

Pleurocorallium secundum—Near Ki and Banda Islands, 140 and 200 fathoms; Sandwich Islands and Japan, depth (?).

Nellia oculata—Heard Island, 75 fathoms; Torres Strait, 28 and 49 fathoms; Philippines, 18 fathoms; Bahia, 10 to 40 fathoms; India and Gulf of Florida, depth (?).

We may now summarise the distribution of the 36 species which extend into other regions of the ocean outside the area represented by these three Stations, as follows :—

Bathymetrical Distribution.—It appears that of these 36 species, 13 species are known to occur only in depths over 150 fathoms (of which 5 species extend into deep water over 1000 fathoms); the remaining 23 species extend into shallow water under 150 fathoms (of which 3 species extend into deep water over 1000 fathoms).

LIST III *e*.

We give here the names of the 23 species which extend into shallow water under 150 fathoms, indicating the 3 species which are also known from deep water over 1000 fathoms by the word "deep" in brackets after the name :—

Axinella erecta (deep).
Gellius carduus.
Myxilla nobilis.
Pleurocorallium secundum.
Primnoisis antarctica.
Thouarella antarctica.
Cribrella simplex.
Amphiura studeri.
Astrotoma agassizii.
Echinus magellanicus (deep).
Cucumaria serrata.
Psolus ephippifer.
Lagisca magellanica.
Arcturides cornutus.
Serolis latifrons.
Puncturella noachina (deep).
Cabèrea darwinii.
Cellepora mamillata.
" *vagans.*
Escharoides occlusa.
Mucronella ventricosa.
Myriozoum marionense.
Nellia oculata.

Geographical Distribution.—Of the 36 species we find that :—

10 species are represented in the Magellan Strait.
9 " " near Kerguelen under 150 fathoms.
8 " " near Marion Island under 150 fathoms.
7 " " near Heard Island.
6 " " in the tropical Pacific.
6 " " in the North Atlantic.
4 " " in the Southern Ocean in deep water.
4 " " near Tristan da Cunha.
4 " " in the North Pacific.
3 " " near the Cape of Good Hope.
3 " " near the Falkland Islands.
3 " " in the tropical Atlantic.

2	species	are represented	near the Rio de la Plata.
2	,,	,,	in the Indian Ocean.
1	,,	,,	near the Auckland Islands.
1	,,	,,	near Australia.
1	,,	,,	near New Zealand.
1	,,	,,	near the Kermadec Islands.
1	,,	,,	in the Arctic Ocean.

Turning now our attention to the 61 genera represented at the Stations under consideration, we find that 4 genera are known only from these Stations, viz. :—*Aulascus*, *Primnoides*, *Cladopathes*, and *Chorismus*; there is also the genus *Polyeunoa*, known, apart from these Stations, only from the Magellan Strait. These 5 genera are each represented by a single species. The genus *Reteporella* (containing 2 species) is known from one of these Stations (148) and from near Heard Island, 75 fathoms.

Examining Contents of Trawl.

LIST IV.

METAZOA PROCURED BY THE CHALLENGER IN SHALLOW WATER, IN DEPTHS LESS THAN 150 FATHOMS, IN THE KERGUELEN REGION.

Let us now consider the shallow-water fauna of the Kerguelen Region of the Great Southern Ocean, taking the depth of 150 fathoms as the limit of the area. The following is a list of the species and varieties of marine Metazoa obtained by the Challenger in the vicinity of the islands of the Kerguelen Region, viz., off Marion and Prince Edward Islands, in 50 to 140 fathoms (six dredgings); off Kerguelen, from the shore to 150 fathoms (many dredgings and trawlings); between Kerguelen and Heard Island, in 150 fathoms (one dredging); and off Heard Island, in 75 fathoms (one dredging). The species known only from these dredgings and trawlings are indicated by an asterisk *.

MONAXONIDA :

**Amphilectus apollinis*,[1] Ridley and Dendy.
* „ *pilosus*,[2] Ridley and Dendy.
**Axinella balfourensis*,[3] Ridley and Dendy.
* „ *mariana*,[4] Ridley and Dendy.
Desmacidon (?) *ramosa*, Ridley and Dendy.
* „ (*Homœodictya*) *kerguelenensis*,[5] Ridley and Dendy.
Gellius carduus, Ridley and Dendy.
* „ *flagellifer*,[6] Ridley and Dendy.

[1] VOSMAER (Sponges of the "Willem Barents" Expedition, 1881–2) has founded a genus *Artemisina* of which the most characteristic spicule is a toxite with spined ends like that which occurs in *Amphilectus apollinis*. Possibly the two species *Artemisina suberitoides*, Vosmaer, and *Amphilectus apollinis*, nobis, come near to one another and may even belong to the same genus, but they differ very widely in the texture of the sponge, and our present species possesses an additional form of megasclera not present in *Artemisina*.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 124.)

[2] This species [*Amphilectus pilosus*] is very well marked, and may be readily recognised both by its external appearance and its spiculation. All the spicules, except the minute isochela, which is unusually small, are of exceptionally large size. The toxa are probably the largest known examples of their kind. Some of them were found still enveloped by the mother-cell. The most interesting feature of the species is, however, the manner in which the toxa appear to develop into oxea.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 127.)

[3] *Axinella balfourensis* seems to be a very aberrant species of the genus, as indicated both by its external form and by the extreme sparseness of the skeleton.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 180.)

[4] *Axinella mariana* is a pretty little species, distinguished by its external form and by the peculiar shape of the smaller stylote spicule, which seems to be homologous with the "vermicular" spicule of *Axinella erecta*, &c.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 180.)

[5] We were at first inclined to regard this sponge [*Desmacidon* (*Homœodictya*) *kerguelenensis*] as a variety of the British species, *Desmacidon* (*Homœodictya*) *palmata*, which it very nearly approaches both in external form and in spiculation. There can be no doubt that the two are closely related, but on the whole it appears better to separate the Kerguelen form as distinct.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 110.)

[6] VOSMAER mentions under "*Gellius vagabundus* (O.S)," in the Sponges of the "Willem Barents" Expedition, a variety of that species possessing oxea and sigmata, similar in form to those of our species. His specimen, though containing a few styli, is obviously a true *Gellius* (*Gellius vagabundus* being *Desmacella* for us), and it is not improbably referable to *Gellius flagellifer*. It was obtained by the "Willem Barents" Expedition of 1880, and hence probably in

Gellius glacialis, var. *nivea*, Ridley and Dendy.
Halichondria panicea, Johnston.
„ sp. (?).
**Iophon abnormalis*, Ridley and Dendy.
Latrunculia apicalis,[1] Ridley and Dendy.
* „ *bocagei*,[1] Ridley and Dendy.
**Myxilla fusca*, Ridley and Dendy.
„ *mariana*, Ridley and Dendy.
**Pachychalina* (?) *pedunculata*,[2] Ridley and Dendy.
**Petrosia hispida*, Ridley and Dendy.
„ *similis*,[3] Ridley and Dendy.
Stylocordyla stipitata (Carter), var. *globosa*, Ridley and Dendy.
Suberites antarcticus, Carter.
„ *caminatus*,[4] Ridley and Dendy.
* „ *microstomus*, Ridley and Dendy.

TETRACTINELLIDA :

**Cinachyra barbata*,[5] Sollas.

the Arctic Sea, though the exact locality is unknown. Having regard to the want of definite characters in this species other than the form of the sigmata, we cannot further insist on the strong resemblance which this form bears to our species, as its locality is so far removed from that of *Gellius flagellifer*.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 43.)

[1] As regards external form it will be seen that *Latrunculia bocagei* is almost indistinguishable from the Kerguelen specimen of *Latrunculia apicalis*, and correspondingly different from *Latrunculia brevis* [Station 320, off the Rio de la Plata, 600 fathoms] ; but in this case we are not inclined to set much value on external form as a specific character, for we have already seen that the specimens of *Latrunculia apicalis* from Kerguelen and from Station 320 respectively, differ in external appearance ; indeed, to judge from the Challenger series of specimens of the genus, it would seem that external appearance depends on the locality, and that all the species from the same locality tend to have a similar external form.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 239.)

[2] *Pachychalina* (?) *pedunculata* resembles in several respects VOSMAER'S *Pachychalina caulifera* (from the Arctic Sea), but it is cylindrical instead of flattened, and the shape of the spicules is different, being slender instead of broadly fusiform. The fibres in *Pachychalina caulifera* appear to contain a good deal more spongin than in the present species ; indeed, it is only doubtfully that we include the latter in the genus at all ; it forms another connecting link between the Renierinæ and Chalininæ, and shows how little value can be placed upon the amount of spongin present for purposes of classification.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 25.)

[3] No doubt the Kerguelen specimen [of *Petrosia similis*] forms a connecting link, but we think it advisable to distinguish between two closely allied species, *Petrosia subtriangularis* and *Petrosia similis*, the former characteristic of West Indian seas, and the latter of the seas south of the Cape. Two well-marked varieties of the latter are described below [one from near the Falklands, the other from the Philippines].—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, p. 11.)

[4] The single specimen [of *Suberites caminatus*] in the collection is attached by a broad base to an empty Brachiopod shell, and terminates in a singular oscular projection at the apex. . . . This is a very pretty and interesting little sponge ; it may be recognised by its external form, and more especially by the projecting, well-marked osculum. . . . We have from Station 320 an interesting series of specimens which should perhaps be considered as belonging to a slight variety of the above species ; they do not, however, appear to be distinct enough from the type to justify us in giving a varietal name. They occur, for the most part, encrusting dead branches of a *Sporadopora*, on which they form colonies, the different cushion-like individuals being united together by their bases. . . . The sponge is further remarkable as forming colonies by continuous gemmation, in a manner very rare in silicious sponges.—(RIDLEY and DENDY, *Zool. Chall. Exp.*, part 59, pp. 198–9.)

[5] Over sixty specimens of this remarkable sponge [*Cinachyra barbata*] were dredged off the shores of Kerguelen. They vary considerably in shape ; the smallest is a prolate ellipsoid, the next a little larger is egg-shaped, both are

**Pœcillastra schulzii*, Sollas.
**Tetilla coronida*, Sollas.
* „ *grandis*, Sollas.
* „ „ var. *alba*, Sollas.

HEXACTINELLIDA :

Rossella antarctica, Carter.

CALCAREA :

**Amphoriscus elongatus*, Poléjaeff.
**Leucetta vera*, Poléjaeff.
Leuconia fruticosa (Haeckel).
* „ *levis*, Poléjaeff.
* „ *ovata*, Poléjaeff.

ALCYONARIA :

**Alcyonium antarcticum*, Wright and Studer.
Lophogorgia flammea (Ellis and Solander).
**Primnoisis ambigua*, Wright and Studer.
* „ *sparsa*, Wright and Studer.
Thouarella variabilis, var. *gracilis*, Wright and Studer.

ACTINIARIA :

Halcampa clavus (Quoy and Gaimard).
* „ *kerguelensis*, Hertwig.
Leiotealia nymphæa (Drayton).
**Scytophorus striatus*, Hertwig.

HYDROIDA :

**Campanularia tulipifera*, Allman.
Eudendrium rameum (Pallas).
* „ *vestitum*, Allman.
**Grammaria insignis*, Allman.
* „ *stentor*, Allman.
**Halecium arboreum*, Allman.
„ *flexile*, Allman.
**Hypanthea aggregata*, Allman.
Obelia geniculata (Linné).
**Plumularia abietina*, Allman.

provided with the characteristic oscules of the species, but without anchoring filaments ; these are present, however, in specimens but very slightly larger, and by the time the sponge has attained a length of 20 mm., they are already matted together into a compact basal lump.—(SOLLAS, *Zool. Chall. Exp.*, part 63, pp. 24–5.)

**Plumularia flabellum*, Allman.
* „ *insignis*, Allman.
**Schizotricha multifurcata*, Allman.
* „ *unifurcata*, Allman.
**Sertularia articulata*, Allman.
* „ *echinocarpa*, Allman.
* „ *exserta*, Allman.
* „ *secunda*, Allman.
**Staurotheca dichotoma*, Allman.

CRINOIDEA :

**Antedon antarctica*, Carpenter.
* „ *australis*, Carpenter.
* „ *exigua*,[1] Carpenter.
* „ *hirsuta*, Carpenter.
**Promachocrinus kerguelensis*, Carpenter.

ASTEROIDEA :

**Asterias meridionalis*, Perrier.
* „ *perrieri*, Smith.
* „ (*Smilasterias*) *scalprifera*, Sladen.
* „ („) *triremis*, Sladen.
Bathybiaster loripes, var. *obesa*, Sladen.
Cribrella simplex, Sladen.
„ „ var. *granulosa*, Sladen.
Crossaster penicillatus, Sladen.
**Echinaster spinulifer*, Smith.
**Gnathaster elongatus*, Sladen.
* „ *meridionalis* (Smith).
Labidiaster annulatus, Sladen.
**Leptoptychaster kerguelenensis*, Smith.
**Pedicellaster hypernotius*, Sladen.
* „ *scaber*, Smith.
**Perknaster densus*, Sladen.
* „ *fuscus*, Sladen.
Porania antarctica, Smith.
* „ *glaber*, Sladen.
„ *spiculata*, Sladen.

[1] *Antedon exigua*, which represents *Antedon tenella* [of northern seas] in the Southern Sea, differs from it in the shortness of the later cirrus-joints and in the characters of the lower pinnules.—(CARPENTER, *Zool. Chall. Exp.*, part 60, p. 179.)

**Pteraster*[1] *affinis*, Smith.
* ,, *rugatus*, Sladen.
* ,, *semireticulatus*, Sladen.
**Retaster peregrinator*, Sladen.
**Solaster subarcuatus*,[2] Sladen.

OPHIUROIDEA :

**Amphiura angularis*, Lyman.
,, *antarctica* (Ljungman).
,, *studeri*, Lyman.
* ,, *tomentosa*, Lyman.
Astrotoma agassizii, Lyman.
Gorgonocephalus pourtalesii, Lyman.
**Ophiacantha imago*,[3] Lyman.
,, *vivipara*, Ljungman.
**Ophioconis antarctica*, Lyman.
Ophiocten amitinum, Lyman.
,, *sericeum*, Ljungman.
**Ophioglypha ambigua*, Lyman.
* ,, *brevispina*,[4] Smith.
* ,, *deshayesi*, Lyman.
* ,, *hexactis*,[5] Smith.
* ,, *intorta*, Lyman.

ECHINOIDEA :

Echinus magellanicus, Phil.
,, *margaritaceus*, Lamarck.
Goniocidaris canaliculata, Agassiz.
Hemiaster cavernosus[6] (Phil.).
Schizaster moseleyi, Agassiz.

[1] With the exception of two Atlantic species, *Pteraster caribbæus* [from the West Indian area] and *Pteraster sordidus* [from the "Talisman" or "Travailleur" dredgings], all the members of this genus are confined to the colder temperate and frigid zones. Notwithstanding its wide range of distribution the genus appears to show only a comparatively small amount of morphological plasticity.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 470.)

[2] *Solaster subarcuatus* is nearly allied to *Solaster endeca* [from the Arctic and North Atlantic], of which it is perhaps the southern representative.—(SLADEN, *Zool. Chall. Exp.*, part 51, p. 457.)

[3] *Ophiacantha mago* represents in the Antarctic zone the Arctic *Ophiacantha anomala*, from which it differs in having a minute slender tentacle scale and only five arms.—(LYMAN, *Zool. Chall. Exp.*, part 14, p. 187.)

[4] Several species inhabiting the seas of the North bear a superficial resemblance to this form [*Ophioglypha brevispina*] :—such are *O. albida*, Forbes, *O. robusta*, Ayres, and *O. nodosa*, Lütken. And besides these *O. Lymani*, Ljungman, from Patagonia, is very like it.—(E. A. SMITH, *Phil. Trans.*, vol. 168, p. 281.)

[5] In colour and general appearance it [*Ophioglypha hexactis*] approaches *O. sarsii*, Lütken, of the Greenland coast, which seems to be its nearest ally ; but these species are so different from one another in detail, that it is needless to specify their distinctions.—(E. A. SMITH, *Phil. Trans.*, vol. 168, p. 280.)

[6] The Challenger series [of *Hemiaster cavernosus*] is so extensive, and shows such a range of variation both in form and in the structure of the petals according to age and sex, that I am quite convinced it is impossible to define the

HOLOTHURIOIDEA[1]:

Chirodota contorta,[2] Ludwig.
**Cucumaria kerguelensis*, Théel.

Kerguelen specimens as a different species [*Hemiaster cordatus*]. Dr STUDER and Mr SMITH enumerate it as a distinct species in their lists of Kerguelen Echinoderms. . . . From the evidence furnished by the large material collected by the Challenger, there seems but little doubt that species which have thus far been distinguished as *Hemiaster australis*, *philippii*, and *cavernosus* are all different stages of growth of one and the same species, but owing to the great difference in structure between the ambulacral petals of the males and females, and the extraordinary changes this species passes through from its youngest stage until it has reached its adult sexual form, it was very natural that these several stages of growth should on scanty material have been regarded as so many distinct species. The coloration of specimens from different localities appears also quite distinct, and in some cases the test and spines are of a light brownish-yellow, in striking contrast to the dark coloured specimens found at other localities.—(AGASSIZ, *Zool. Chall. Exp.*, part 9, pp. 183–4.)

[1] The examination of the vast harvest brought home by the Challenger Expedition from different regions of the world, from the shore as well as from the abysses of the ocean, shows clearly that those Holothurids which live in the deep sea have two different derivations. The great majority are Elasipoda, which cannot be derived from the present shallow-water fauna, but must have originated from a past type that certainly bore another stamp. On the other hand, so far as can be judged from the results of the expeditions hitherto made, the remaining Holothurids met with in the great depths are comparatively few, both in species and individuals, and unmistakably show the closest relation to the present shallow-water fauna; so that while the Elasipoda have retired toward the abysses an infinitely long time ago, the latter have emigrated only at a comparatively much later period. . . . With regard to the bathymetrica distribution of Apoda and Pedata, our present knowledge does not enable us to speak of any results of very general value. However, the Challenger Expedition has been successful even in these respects, several important discoveries having been made, proving that the present shallow-water fauna has far more outposts in the great depths of the ocean than at first supposed. Before the Challenger Expedition set out, only a very few forms belonging to the Apoda and Pedata were known from depths exceeding 100 fathoms, and scarcely one below 200 fathoms. This list [of the species met with in the deep sea at depths from 500 fathoms and under] induces me to believe the following remarks to be true, or, at least, to have some probability:

1. Descendants of the recent shallow-water Holothurioidea have escaped to the greatest depths at which any living Holothurid has been obtained, viz., 2900 fathoms, but they are by no means so prevalent as the Elasipoda, nor do they form such a characteristic feature in the abyssal fauna.

2. Most of the forms met with in the deep sea below 500 fathoms are distinct from the shallow-water species though they belong to the same genera.

3. Several species have a vast bathymetrical distribution, some individuals of them still living near the shore, others having descended without any obvious change in their organisation into the considerable depth of 500 to 700 fathoms or exceptionally even deeper.

4. A wider distribution seawards of a species seems to take place preferably in the northern and southern oceans, where the different belts proceeding from the vicinity of land outwards would seem to have in general a greater uniformity in temperature and other physical conditions than in the tropical and subtropical regions, where it is stated that the belts below 100 or 200 fathoms have lost the influence of the climate, etc., and present conditions of life far different from those above them. Such forms are *Myrotrochus rinkii* from shore to 500 fathoms; *Echinocucumis typica* from about 40 to 530 fathoms; *Thyone raphanus* from 20 to 672 fathoms; *Holothuria intestinalis* from 10 to 650 fathoms; *Holothuria tremula* from 20 to 672 fathoms; *Trochostoma violacea* from 20 to 700 fathoms; *Thyonidium pellucidum* from about 30 to 1081 fathoms, etc. The two deep-sea species of *Synapta* are scarcely distinguishable from some of the shallow-water species.

5. *Pœlopatides*, *Pseudostichopus*, *Acanthotrochus* and probably even *Ankyroderma* are the only true deep-sea genera of Apoda and Pedata, no representatives of them having hitherto been obtained near the shore or, at least, from any trifling depth. Species of these genera very seldom seem to thrive at a less depth than 500 fathoms.

6. Among the Apoda the Synaptidæ are, with a very few exceptions, shore forms, living near the surface of the sea, while the Molpadidæ are probably in a state of emigration seawards, a great number of them having already reached the abysses and settled there.

7. The Dendrochirotæ and Aspidochirotæ are still true shore or shallow-water forms, though there are even here many exceptions, proving that their representatives are thriving even at great depths.—(THÉEL, *Zool. Chall. Exp.*, part 39, pp. 1, 2, 6, 7.)

[2] It is remarkable that the forms [of *Chirodota purpurea*] dredged at the Falkland Islands are devoid of any sigmoid deposits, while those found by the Challenger Expedition in the Strait of Magellan and at Kerguelen

**Cucumaria lævigata* (Verrill).
„ *serrata*, Théel.
„ „ var. *intermedia*, Théel.
„ „ var. *marionensis*, Théel.
Pseudostichopus moliis, Théel.
Psolus ephippifer, Wyville Thomson.
* „ *incertus*, Théel.
**Thyone recurvata*, Théel.
**Trochostoma violaceum*, Studer.

ENTOZOA :

Ascaris simplex, Rudolphi.
„ *spiculigera*, Rudolphi.

NEMERTEA :

**Amphiporus marioni*, Hubrecht.
* „ *moseleyi*, Hubrecht.
**Cerebratulus corrugatus* (M'Intosh).
* „ *longifissus*, Hubrecht.
„ sp. (?).
Drepanophorus serraticollis, Hubrecht.

GEPHYREA :

**Phascolosoma pudicum*, Selenka.

ANNELIDA :

**Ampharete kerguelensis*, M'Intosh.
**Amphitrite kerguelensis*, M'Intosh.
**Artacama challengeriæ*, M'Intosh.
**Autolytus macleariranus*, M'Intosh.
**Brada mammillata*, Grube.

Island have, as a rule, such deposits. Therefore it seems to me far more credible that *Holothuria purpurea* of LESSON, which was also obtained at Falkland Islands (Soledad), is identical with the above described forms rather than with STUDER'S *Sigmodota purpurea* [re-named by THÉEL *Chirodota studerii*], which is found living in the Strait of Magellan and at Kerguelen Island. . . . The specimens [of *Chirodota contorta*] brought home from Station 314 [Falklands] differ from the others in having the aggregations of wheels much more crowded, while the aggregations of wheels, especially in the individuals obtained at Marion Island, are very scattered, so that they almost appear at first sight to be devoid of them. The specimens examined by me differ from LUDWIG'S type in their violet colour. It seems very peculiar that all the individuals dredged by the Challenger Expedition in several localities at the Kerguelen Islands, as well as in or in the neighbourhood of the Strait of Magellan, belong to LUDWIG'S *Chirodota contorta*. Not a single specimen of STUDER'S *Sigmodota purpurea* was obtained, therefore I cannot help thinking that the very scattered aggregations of wheels have escaped the attention of STUDER, because of the sigmoid bodies being so conspicuous by their number as well as by their size.—(THÉEL, *Zool. Chall. Exp.*, part 39, pp. 15-16.)

**Ereutho kerguelensis*, M'Intosh.
Eulagisca corrientis, M'Intosh.
**Eunice edwardsi*, M'Intosh.
,, *magellanica*, M'Intosh.
,, *ærstedi*, Stimpson.
**Eupolynoë mollis*, M'Intosh.
**Eusyllis kerguelensis*, M'Intosh.
**Evarne kerguelensis*, M'Intosh.
**Exogone heterosetosa*, M'Intosh.
**Glycera kerguelensis*, M'Intosh.
Hermadion kerguelensis, M'Intosh.
Lætmonice producta, Grube.
,, ,, var. *wyvillei*, M'Intosh.
**Lagisca antarctica*, M'Intosh.
,, *magellanica*, M'Intosh.
**Lumbriconereis kerguelensis*,[1] Grube.
Neottis antarctica, M'Intosh.
**Nephthys trissophyllus*, Grube.
**Nereis kerguelensis*, Baird.
,, (*Platynereis*) *eatoni*,[2] M'Intosh.
Notomastus (?) sp.
Phyllocomus crocea, Grube.
**Polycirrus kerguelensis*, M'Intosh.
**Praxilla assimilis*, M'Intosh.
* ,, *kerguelensis*, M'Intosh.
**Salvatoria kerguelensis*, M'Intosh
Scolecolepis cirrata, Sars.
**Scoloplos kerguelensis*, M'Intosh.
Serpula narconensis, Baird.
**Sphærosyllis kerguelensis*, M'Intosh.
Spirorbis sp. (?).
**Syllis gigantea*, M'Intosh.
Terebella (*Lanice*) *flabellum*, Baird.
Terebellides strœmi, Sars, var. *kerguelensis*, M'Intosh.
**Travisia kerguelensis*, M'Intosh.
**Trophonia kerguelarum*, Grube.

[1] *Lumbriconereis kerguelensis* evidently takes the place of the European *Lumbriconereis nardonis*, to which it is closely allied in the structure of the dental apparatus.—(M'Intosh, *Zool. Chall. Exp.*, part 34, p. 247.)

[2] This form [*Nereis* (*Platynereis*) *eatoni*], which was first procured by Rev. Mr Eaton, of the Transit of Venus Expedition, seems to take the place of *Nereis dumerilii*, Aud. and Ed., of the European seas, and indeed it is allied in a very close manner to the latter species.—(M'Intosh, *Zool. Chall. Exp.*, part 34, p. 224.)

OSTRACODA :

**Aglaia* (?) *obtusata*, Brady.
Argillæcia eburnea, Brady.
**Bairdia simplex*, Brady.
,, *victrix*, Brady.
,, *villosa*, Brady.
Bythocypris reniformis, Brady.
**Bythocythere pumilio*, Brady.
**Cypridina danæ*, Brady.
Cythere audei, Brady.
,, *dictyon*, Brady.
* ,, *foveolata*,[1] Brady.
Cythere kerguelenensis,[2] Brady.
,, *normani*, Brady.
* ,, *parallelogramma*, Brady.
,, *polytrema*,[3] Brady.
* ,, *securifer*, Brady.
* ,, *subrufa*, Brady.
,, *suhmi*, Brady.
,, *wyville-thomsoni*, Brady.
**Cytherideis lævata*, Brady.
Cytheropteron (?) *angustatum*, Brady.
* ,, *assimile*,[4] Brady.
,, *fenestratum*, Brady.
* ,, *scaphoides*,[5] Brady.
**Cytherura costellata*, Brady.
* ,, *lilljeborgi*,[6] Brady.

[1] The general form of this species [*Cythere foveolata*] is very familiar ; many might be named which approach it rather closely, but no described species seems to be absolutely identical with it. The nearest, perhaps, are *Cythere borealis*, Brady—an Arctic form,—and *Cythere œdichilus*, Brady, a fossil of the Antwerp Crag.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 76.)

[2] Seen on the dorsal surface, this species [*Cythere kerguelenensis*] bears a close resemblance to the common British *Cythere albomaculata*, Baird, but the shell is much more coarsely sculptured, while the spinous margins and very broadly reniform lateral outline are constant distinctive characters.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 79.)

[3] A few detached valves brought by the Challenger from off Prince Edward Island in the Southern Ocean are in no respect distinguishable from the fossil specimens described by me in a Monograph of the Fossil Ostracoda of the Antwerp Crag, under the name *Cythere polytrema*. It is extremely interesting to note the occurrence, alive in this distant region, of so well marked a European fossil.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 87.)

[4] Though bearing considerable resemblance to the northern species *Cytheropteron latissimum* (Norman), this [*Cytheropteron assimile*] is easily distinguished by the character of the surface-sculpture, which shows no tendency to run into transverse grooves ; the lateral alæ, too, are considerably more prominent.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 139.)

[5] *Cytheropteron scaphoides* is not unlike in general character to *Cytheropteron subcircinatum*, Sars, but is very much less tumid.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 136.)

[6] The nearest known ally [of *Cytherura lilljeborgi*] is probably *Cytherura clathrata*, Sars, with which it closely agrees in style of surface-sculpture though quite different in proportions and general contour.—(BRADY, *Zool. Chall. Exp.*, part 4, p. 133.)

**Cytherura obliqua*, Brady.
Krithe bartonensis (Jones).
„ *producta*, Brady.
Macrocypris decora, Brady.
„ *maculata*, Brady.
„ *tumida*, Brady.
Paradoxostoma abbreviatum, Sars.
Polycope orbicularis, Sars.
Pseudocythere caudata, Sars.
Sclerochilus contortus (Norman).
Xestoleberis curta, Brady.
„ *depressa*, Sars.
* „ *setigera*, Brady.
**Xiphichilus complanatus*, Brady.

CIRRIPEDIA :

**Balanus corolliformis*,[1] Hoek.
**Scalpellum recurvirostrum*, Hoek.

AMPHIPODA[2] :

**Acanthechinus tricarinatus*, Stebbing.
**Acontiostoma kergueleni*, Stebbing.
* „ *marionis*, Stebbing.
* „ *pepinii*, Stebbing,
**Ambasia integricauda*, Stebbing.
**Amphilochus marionis*,[3] Stebbing.
**Amphithoë kergueleni*, Stebbing.

[1] *Balanus hirsutus* [taken by H.M.S. "Triton" in the Faroe Channel, 516 fathoms] and *Balanus corolliformis* [from Station 150, 150 fathoms] are two nearly related species, corresponding in all essential respects. I must consider them, however, as different species, because their shape is quite different, and in the second place, because the tergum shows very striking differences also. . . . *Balanus corolliformis* is a very remarkable species, and I confess to have been long in doubt whether it was a *Balanus* or not. The investigation of specimens of a nearly related form [*Balanus hirsutus*], which showed the same characteristic differences from the other species of the genus, convinced me that I was right in considering them as representatives of a new section of the genus *Balanus*.—(HOEK, *Zool. Chall Exp.*, part 25, pp. 155, 6, 8.)

[2] To judge by the results obtained at Kerguelen Island in the Southern Ocean it is much rather in Antarctic than in Arctic waters that the explorer who devotes himself to the search after Amphipoda may hope to find new and surprising forms. There are, it is true, some remarkable instances in which the same species occurs both far north and far south, but these are after all not very numerous.—(T. R. R. STEBBING, "The Amphipoda collected during the voyages of the Willem Barents in the Arctic Seas in the years 1880–1884," *Bijdragen tot de Dierkunde*, Afl. 17, p. 1, 1894.)

[3] A specimen of *Amphilochus* from the Clyde, kindly sent me by Mr DAVID ROBERTSON, agrees in most respects with BOECK'S description of his *Amphilochus tenuimanus*, and has also a great resemblance to the present species [*Amphilochus marionis*] ; the maxillipeds in the Scotch form and in that from the Southern Ocean are remarkably alike. . . . altogether the sum of the differences, added to the great distance between the localities at which the specimens occur, makes it unsafe to place the northern and southern examples in one and the same species.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 746.)

**Anonyx cicadodes*, Stebbing.
**Aora kergueleni*, Stebbing.
* „ *trichobostrychus*, Stebbing.
Atyloides australis (Miers).
**Autonoe kergueleni*, Stebbing.
**Cardenio paurodactylus*, Stebbing.
**Cerapus sismithi*, Stebbing.
**Cheirimedon crenatipalmatus*, Stebbing.
**Dodecas elongata*, Stebbing.
**Eusiroides pompeii*, Stebbing.
Eusirus longipes,[1] Boeck.
Euthemisto thomsoni,[2] Stebbing.
**Gammaropsis exsertipes*, Stebbing.
**Halimedon schneideri*, Stebbing.
**Haplocheira plumosa*, Stebbing.
**Harpinia obtusifrons*, Stebbing.
**Harpinioides drepanocheir*, Stebbing.
**Hippomedon kergueleni* (Miers).
* „ *trigonicus*, Stebbing.
**Iphimedia pacifica*, Stebbing.
* „ *pulchridentata*, Stebbing.
**Kerguelenia compacta*, Stebbing.
**Lepidepecreum foraminiferum*, Stebbing.
**Liljeborgia consanguinea*,[3] Stebbing.
**Metopa nasutigenes*,[4] Stebbing.
**Neohela serrata*, Stebbing.
**Œdiceroides rostrata*, Stebbing.
**Orchomene cavimanus*,[5] Stebbing.
**Pardalisca marionis*,[6] Stebbing.
**Photis macrocarpus*, Stebbing.
**Phoxocephalus kergueleni*, Stebbing.

[1] I cannot find any points of difference that would justify the separation of this southern species from the northern *Eusirus longipes*, Boeck.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 969.)

[2] *Euthemisto thomsoni* appears to stand extremely near to the northern *Euthemisto bispinosa* (Boeck).—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 1416.)

[3] The specific name [of *Liljeborgia consanguinea*] refers to the obviously very close relationship between this southern species and the northern *Liljeborgia pallida*, Spence Bate.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 984.)

[4] *Metopa nasutigenes* is very like *Metopa nasuta*, Boeck [a northern species], which also has the large beak or nose formed by the first joint of the upper antennæ. Hence the specific name is a hybrid, to express "of the lineage of *nasuta*."—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 756.)

[5] In the course of the description the differences have been noticed between this [*Orchomene cavimanus*] and the very similar species, *Orchomene musculosus*, taken at an enormously distant Station to the south of Japan.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 681.)

[6] This species from the south [*Pardalisca marionis*] is remarkably like the northern species *Pardalisca cuspidata*.—(STEBBING, *Zool. Chall. Exp.*, part 67, p. 999)

**Platophium danæ*, Stebbing.
Podocerus falcatus[1] (Montagu).
**Protellopsis kergueleni*, Stebbing.
**Rhachotropis kergueleni*, Stebbing.
**Socarnoides kergueleni*, Stebbing.
**Sophrosyne murrayi*, Stebbing.
**Tritæta kergueleni*, Stebbing.
**Tryphosa antennipotens*, Stebbing.
* ,, *barbatipes*, Stebbing,
**Urothoë lachneëssa*, Stebbing.

ISOPODA :

**Anceus gigas*, Beddard.
* ,, *tuberculosus*, Beddard.
**Apseudes antarctica*, Beddard.
* ,, *spectabilis*, Studer.
Arcturus furcatus, Studer.
* ,, *stebbingi*, Beddard.
* ,, *studeri*, Beddard.
**Astacilla marionensis*, Beddard.
**Astrurus crucicauda*, Beddard.
Cymodocea darwini, Cunningham.
**Ilyarachna quadrispinosa*, Beddard.
Jæra pubescens, Dana.
**Jæropsis marionis*, Beddard.
**Leptognathia australis*,[2] Beddard.
**Munna*[3] *maculata*, Beddard.
* ,, *pallida*, Beddard.
Neasellus kerguelenensis, Beddard.
**Paranthura neglecta*, Beddard.
**Paratanais dimorphus*, Beddard.
**Pleurogonium albidum*,[4] Beddard.
* ,, *serratum*,[4] Beddard.

[1] Speaking of *Podocerus falcatus*, STEBBING says: There is the possibility, as I have elsewhere suggested, that these creatures may have travelled out from our own waters along with the vessel to the southern latitudes at which they were captured.—(*Zool. Chall. Exp.*, part 67, p. 1135.)

[2] This species [*Leptognathia australis*] is probably new, but agrees very closely with *Leptognathia longiremis*, Sars, from the Norwegian North Atlantic Expedition.—(BEDDARD, *Zool. Chall. Exp.*, part 48, p. 127.)

[3] Only five species of this genus [*Munna*] are at present known, all of which are inhabitants of the shallow water off the coasts of Great Britain, Norway, North America, &c.; in the present Report I have two new species to add, both of which are from shallow water off Kerguelen.—(BEDDARD, *Zool. Chall. Exp.*, part 48, p. 24.)

[4] *Pleurogonium albidum* and *Pleurogonium serratum* [from Kerguelen] evidently come very near to SARS' *Pleurogonium rubicundum* [from Norway].—(BEDDARD, *Zool. Chall. Exp.*, part 48, p. 28.)

Serolis cornuta, Studer.
„ *latifrons*, White.
„ *septemcarinata*, Miers.
**Tanais hirsutus*, Beddard.
* „ *willemœsii*, Studer.
Typhlotanais kerguelenensis, Beddard.
About twelve species of Isopoda undetermined.

CUMACEA :

**Campylaspis nodulosa*,[1] Sars.
**Diastylis horrida*,[2] Sars.
**Leucon assimilis*,[3] Sars.
**Paralamprops serrato-costata*, Sars.
**Vaunthompsonia meridionalis*, Sars.

SCHIZOPODA :

Euphausia murrayi, Sars.
Pseudomma sarsii, Suhm.

MACRURA :

Campylonotus capensis, Bate.
Nauticaris marionis, Bate.

ANOMURA :

Parapagurus dimorphus (Studer).

BRACHYURA :

Halicarcinus planatus (Fabricius).

PYCNOGONIDA :

Colossendeis megalonyx,[4] Hoek.
* „ *robusta*, Hoek.
**Nymphon brachyrhynchus*,[5] Hoek.

[1] The Norwegian form *Campylaspis verrucosa* would seem to be nearly related to the present species [*Campylaspis nodulosa*], at least as regards the sculpture of the carapace.—(SARS, *Zool. Chall. Exp.*, part 55, p. 68.)

[2] In general appearance *Diastylis horrida* would seem to be most nearly related to the northern form *Diastylis lucifera* (Kröyer).—(SARS, *Zool. Chall. Exp.*, part 55, p. 55.)

[3] *Leucon assimilis* is very nearly allied to the northern species *Leucon nasicus*, Kröyer, from which it may, however, be distinguished by the somewhat different form of the pseudorostral projection.—(SARS, *Zool. Chall. Exp.*, part 55, p. 34.)

[4] *Colossendeis megalonyx* resembles *Colossendeis proboscidea* (Sabine) [from the Arctic] in the form of the proboscis. That species, however, is a great deal stouter, and has a much larger body with comparatively short legs.—(HOEK, *Zool. Chall. Exp.*, part 10, p. 69.)

[5] In some respects *Nymphon brachyrhynchus* shows a resemblance to *Nymphon strœmii* of KRÖYER [from the Arctic and North Atlantic].—(HOEK, *Zool. Chall. Exp.*, part 10, p. 48.)

**Nymphon brevicaudatum*,[1] Miers.
* ,, *fuscum*, Hoek.

LAMELLIBRANCHIATA :

Anatina elliptica, King and Broderip.
Astarte magellanica, Smith.
**Cardita astartoides*,[2] Martens.
**Crenella marionensis*, Smith.
**Cryptodon marionensis*,[3] Smith.
**Dacrydium meridionalis*, Smith.
**Davila* (?) *umbonata*, Smith.
**Kellia cardiformis*, Smith.
* ,, *nuculina*, Martens.
,, *suborbicularis*[4] (Montagu).
Lima (*Limatula*) *pygmæa*, Philippi.
**Limopsis marionensis*, Smith.
* ,, *straminea*, Smith.
**Malletia gigantea*, Smith.
**Modiolarca kerguelensis*, Smith.
,, *trapezina* (Lamarck).
**Mytilus kerguelensis*, Smith.
,, *magellanicus*, Chemnitz.
* ,, *meridionalis*, Smith.
**Neæra* [= *Cuspidaria*] *kerguelenensis*, Smith.
**Pecten aviculoides*, Smith.
* ,, *clathratus*, Martens.
* ,, *distinctus*, Smith.
Saxicava arctica,[5] Linné.

[1] This species [*Nymphon brevicaudatum*] is allied to the boreal *N. brevitarse*, Kröyer ; but it is distinguished by its more robust form, its long and slender oculigerous tubercle, its longer tarsal joints, &c.—(E. J. MIERS, *Phil. Trans.*, vol. 168, p. 213.)

[2] *Cardita astartoides*, as pointed out by MARTENS, bears a great resemblance to the North American *Cardita borealis*, and may be regarded as the southern representative of that form. It certainly is more like that species than *Cardita velutina* from South Patagonia, which we should not expect, considering how similar the fauna of that region and of Kerguelen Island appear to be.—(SMITH, *Zool. Chall. Exp.*, part 35, pp. 212, 213.)

[3] *Cryptodon marionensis* is the southern form of *Cryptodon gouldii*, Philippi, and *Cryptodon flexuosus*, Montagu, both of which species it closely resembles.—(SMITH, *Zool. Chall. Exp.*, part 35, p. 194.)

[4] Two specimens from Kerguelen I cannot distinguish from this well-known European species [*Kellia suborbicularis*], which has not, I believe, been previously met with farther south than the Canaries.—(SMITH, *Zool. Chall. Exp.*, part 35, p. 201.)

[5] This polymorphous species [*Saxicava arctica*], judging from the shells alone, is apparently distributed all ove the globe. Of the animals inhabiting them we know nothing except those of northern varieties. The shells vary immensely in form, thickness, and ornamentation. Those found off the South African coast are especially remarkable for the great development of the spines on the posterior side, and have been raised to specific rank by Mr SOWERBY under the name of *Saxicava spinifera*. Many localities have already been cited for this species, and among them may

**Thracia meridionalis*,[1] Smith.
**Yoldia isonota*, Martens.
* ,, *subæquilateralis*, Smith.

SCAPHOPODA AND GASTEROPODA :

**Actæon* (*Acteonina*) *edentulus*, Watson.
**Alaba* (*Diala*) *limnæiformis*, Watson.
,, (,,) sp. (?).
**Buccinum albozonatum*, Watson.
**Cancellaria* (*Admete*) *carinata*, Watson.
* ,, (,,) *specularis*, Watson.
,, (,,) sp. (?).
Cerithium sp. (?).
Cyclostrema sp. (?).
**Dentalium ægeum*, Watson.
,, *entalis*, Linné, var. *orthrum*, Watson.
**Eatoniella caliginosa* (Smith).
* ,, *subrufescens* (Smith).
Emarginula sp. (?).
**Eulima amblia*, Watson.
**Fusus* (*Euthria*) *chloroticus*, Martens.
,, (,,) *fuscatus* (Bruguière).
* ,, (*Neptunea*) *edwardiensis*, Watson.
* ,, (,,) *regulus*, Watson.
* ,, (*Sipho*) *futile*, Watson.
Homalogyra atomus[2] (Philippi).
Hydrobia caliginosa (Gould).
Lamellaria sp. (?).
**Litorina setosa*, Smith.
**Natica fartilis*,[3] Watson.
* ,, *grisea*, Martens.

be mentioned Greenland, Norway, Great Britain, Sitka, Japan, California, Peru, Patagonia, Canaries, Madeira, Mogador, Mediterranean, Madagascar, Cape of Good Hope, Australia, New Zealand, &c. ; and it is also found fossil in several Upper Tertiary formations.—(SMITH, *Zool. Chall. Exp.*, part 35, p. 78.)

[1] *Thracia meridionalis* is the southern representative of the Greenlandic species *Thracia truncata*, and indeed differs so slightly from it that it is with considerable hesitation I venture to describe it as distinct, being mainly influenced to do so by the difference of locality.—(SMITH, *Zool. Chall. Exp.*, part 35, p. 69.)

[2] The step from Madeira to lat. 46° S. is so enormous, that I was glad to have my identification of the specimen [of *Homalogyra atomus*] confirmed by one who knows the species so well as Dr GWYN JEFFREYS does. It is extremely abundant in Madeira, and careful search will probably supply very many additional localities for its dwelling.—(WATSON, *Zool. Chall. Exp.*, part 42, p. 121.)

[3] *Natica fartilis* so closely approaches *Natica affinis* [a northern species] that I have hesitated very much to separate them, and have been glad to be strengthened in so doing by the opinion of Professor VON MARTENS and Mr E. A. SMITH.—(WATSON, *Zool. Chall. Exp.*, part 42, p. 447.)

**Natica xantha*, Watson.
* „ (*Amauropsis*) *perscalpta*, Martens.
* „ („) *suturalis*,[1] Watson.
„ (*Lunatia*) *grönlandica*,[2] Beck.
* „ („) *prasina*, Watson.
**Neobuccinum eatoni*, Smith.
* „ *vestitum* (Martens).
Odostomia rissoïdes,[3] Hanley.
Patella fuegiensis, Reeve.
* „ *kerguelensis*, Smith.
**Pleurotoma* (*Spirotropis*) *studeriana*, Martens.
„ (*Surcula*) *staminea*, Watson.
* „ („) *trilix*, Watson.
* „ (*Thesbia*) *corpulenta*, Watson.
* „ („) *platamodes*, Watson.
* „ („) *translucida*, Watson.
* „ (*Typhlomangelia*) *fluctuosa*, Watson.
* „ („) „ var. *cariosa*, Watson.
„ sp. (?).
**Provocator pulcher*, Watson.
Puncturella noachina (Linné), var. *princeps*, Mighels.
**Rissoa* (*Ceratia*) *transenna*, Watson.
* „ (*Setia*) *australis*, Watson.
* „ („) *edwardiensis*, Watson.
* „ („) *marionensis*, Watson.
* „ („) *principis*, Watson.
* „ („) *sinapi*, Watson.
Scissurella crispata, Fleming.
* „ *obliqua*, Watson.
**Skenea subcanaliculata*, Smith.
**Struthiolaria mirabilis*, Smith.
Triton (*Lagena*) *magellanicus* (Chemnitz).

[1] *Natica* (*Amauropsis*) *suturalis* has so strongly the aspect of *Natica islandica* that I can easily believe connecting links will yet establish their identity. The age of *Natica islandica* and its distribution, as well as its present habitat in Subarctic and Arctic seas, make its presence in Antarctic regions more probable. But for the present it is impossible to unite them.—(Watson, *Zool. Chall. Exp.*, part 42, p. 456.)

[2] On comparing this [*Natica* (*Lunatia*) *grönlandica* from Heard Island] with Sars' specimens from Norway I am not quite satisfied, and yet I cannot part them. . . . It was unsatisfactory to put a Kerguelen shell to an Arctic species without fuller conviction, and I was glad, therefore, to have my determination of the species confirmed by Mr E. A. Smith.—(Watson, *Zool. Chall. Exp.*, part 42, p. 448.)

[3] I give this species [*Odostomia rissoides* from Marion Island] on the authority of Dr Gwyn Jeffreys. I had remarked the shell's great resemblance in form to *Odostomia rissoïdes*, but the distinct and strong spiral structure which characterises it, coupled with the locality, prevented my referring it to that species.—(Watson, *Zool. Chall. Exp.*, part 42, p. 481.)

Triton (*Lagena*) sp. (?).
**Trochus* (*Margarita*) *charopus*, Watson.
* „ („) „ var. *cæruleus*, Watson.
„ (*Photinula*) *expansus* (Sowerby).
**Trophon albolabratus*, Smith.
* „ *declinans*,[1] Watson.
„ *geversianus* (Pallas).
**Trophon scolopax*, Watson.
* „ *septus*, Watson.
„ sp. (?)
**Turritella austrina*,[2] Watson.
* „ *incolor*, Smith.
**Volutomitra fragillima*, Watson.

POLYPLACOPHORA :

**Hemiarthrum setulosum*, Carpenter, MS.
**Leptochiton kerguelensis*, Haddon.

NUDIBRANCHIATA :

**Archidoris*[3] *australis*, Bergh.
* „ *kerguelenensis*, Bergh.

MARSENIADÆ :

**Marseniopsis murrayi*, Bergh.
* „ *pacifica*, Bergh.

CEPHALOPODA :

**Octopus levis*, Hoyle.

POLYZOA :

**Amphiblestrum cristatum*, Busk.
Bicellaria pectogemma, Goldstein.
**Bugula longissima*, Busk.
* „ *sinuosa*, Busk.
Caberea darwinii, Busk.
Carbasea ovoidea, Busk.

1 I have described this [*Trophon declinans*] as a new species with very great reluctance. My own opinion is that it is a large thin variety of *T. truncatus*, Ström; and that opinion is shared by Mr E. A. SMITH. Dr GWYN JEFFREYS, however, and Professor G. O. SARS decidedly hold it as distinct; and their extensive acquaintance with the large northern variety of *T. truncatus* makes their judgment of great weight.—(WATSON, *Zool. Chall. Exp.*, part 42, pp. 168–9.)

2 *Turritella austrina* is very like our British *T. terebra*, Linné, but is stumpier in form, smaller, with a much more impressed suture, and fewer spiral threads.—(WATSON, *Zool. Chall. Exp.*, part 42, p. 471.)

3 BERGH enumerates two species of *Archidoris* from the North Atlantic, one species from the North Pacific, and two new species from Kerguelen.—(*Zool. Chall. Exp.*, part 26, p. 85.)

**Catenaria attenuata*, Busk.
Cellepora albirostris (Smitt).
„ *bicornis*, Busk.
„ *eatonensis*, Busk.
„ *pustulata*, Busk.
**Cellularia elongata*, Busk.
* „ *quadrata*, Busk.
Chorizopora hyalina, var. *bougainvillei*, d'Orbigny.
Cribrilina monoceros (Busk).
„ *philomela*, Busk.
„ „ var. *adnata*, Busk.
Crisia eburnea (Linné), var. *laxa*, Busk.
„ *holdsworthii*, Busk.
Diachoris inermis, Busk.
„ *magellanica*, Busk, var. *distans*, Busk.
**Electra cylindracea*, Busk.
Escharoides verruculata (Smitt).
**Flustra crassa*, Busk.
Flustramorpha marginata (Krauss).
Hippothoa flagellum, Manzoni.
Hornera violacea, Sars.
Idmonea atlantica, Forbes.
„ *australis*, MacGillivray.
„ *marionensis*, Busk.
„ *milneana*, d'Orbigny.
Membranipora crassimarginata (Hincks), var. *erecta*, Busk.
„ *galeata*, Busk.
„ „ var. *furcata*, Busk.
Menipea benemunita, Busk.
„ *flagellifera*, Busk.
„ *marionensis*, Busk.
**Mucronella rostrigera*, Busk.
„ *tricuspis*, Hincks.
„ *ventricosa*, var. *multispinata*, Busk.
Myriozoum marionense, Busk.
Nellia oculata, Busk.
Onchopora sinclairii, Busk.
Pustulopora deflexa (Smitt).
„ *proboscidea*, M.-Edwards.
„ *proboscidioides* (Smitt).
**Reteporella flabellata*, Busk.

Salicornaria clavata, Busk.
„ *malvinensis*, Busk.
„ *variabilis*, Busk.
Schizoporella marsupifera, Busk.
„ *triangula*, Hincks.
Smittia jacobensis, Busk.
* „ *marionensis*, Busk.
**Supercytis tubigera*, Busk.
**Vincularia gothica*, d'Orbigny.
* „ „ var. *granulata*, Busk.

BRACHIOPODA :

Platydia anomioides (Scacchi).
Rhynchonella nigricans (Sowerby), var. *pixydata*, Watson.
Terebratella dorsata (Gmelin).
Terebratula uva, Broderip.
Terebratulina caput-serpentis, Linné, var. *septentrionalis*, Couthouy.
**Waldheimia kerguelenensis*, Davidson.

TUNICATA :

**Amaroucium complanatum*, Herdman.
* „ *globosum*, Herdman.
* „ *nigrum*, Herdman.
* „ *variabile*,[1] Herdman.
* „ „ var. *tenerum*, Herdman.
Aplidium fumigatum, Herdman.
* „ *fuscum*, Herdman.
* „ *leucophæum*, Herdman.
**Ascidia challengeri*,[2] Herdman.
* „ *despecta*, Herdman.
* „ *placenta*, Herdman.
* „ *translucida*, Herdman.
* „ *vasculosa*, Herdman.
**Ascopera gigantea*, Herdman.
* „ *pedunculata*, Herdman.

[1] I unite under this species [*Amaroucium variabile*] a large number of specimens, collected in the neighbourhood of Kerguelen Island, which present great variations in form, size, colour, and some other particulars. They are, however, all closely related to one another, and although it might be possible to break them up into two or three species, I believe that the differences between the extreme forms are sufficiently bridged over by intermediate conditions to warrant one in regarding them as composing a single species only. They form an extremely interesting series on account of the way in which they illustrate individual variation.—(HERDMAN, *Zool. Chall. Exp.*, part 37, p. 216.)

[2] *Ascidia challengeri* is a large and somewhat variable species, which appears to be common at Kerguelen Island. In the first part of the Preliminary Report it was considered as being identical with *Ascidia mentula*, O. F. Müller, a species to which it is closely allied.—(HERDMAN, *Zool. Chall. Exp.*, part 16, p. 203.)

**Chorizocormus reticulatus*, Herdman.
**Colella concreta*, Herdman.
,, *pedunculata* (Quoy and Gaimard).
* ,, *quoyi*, Herdman.
**Eugyra kerguelenensis*, Herdman.
**Leptoclinum rubicundum*, Herdman.
* ,, *subflavum*, Herdman.
**Molgula pedunculata*, Herdman.
**Morchellioides affinis*, Herdman.
**Morchellium giardi*, Herdman.
**Polycarpa minuta*, Herdman.
**Polyclinum minutum*, Herdman.
* ,, *pyriformis*, Herdman.
**Psammaplidium retiforme*, Herdman.
**Sidnyum pallidum*, Herdman.
**Styela convexa*, Herdman.
* ,, *grandis*, Herdman.
* ,, *lactea*, Herdman.
**Tylobranchion speciosum*, Herdman.
*———(?) *pyriformis*, Herdman (genus doubtful).

FISHES[1]:

Chœnichthys rhinoceratus, Rich.
Harpagifer bispinis, Forst.
**Murænolepis marmoratus*, Günther.
**Notothenia acuta*, Günther.
,, *cyaneobrancha*, Rich.
* ,, *marionensis*, Günther.
* ,, *mizops*, Günther.
* ,, *squamifrons*, Günther.
**Raja eatoni*, Günther.
* ,, *murrayi*, Günther.
**Zanclorhynchus spinifer*,[2] Günther.

[1] The study of the Antarctic surface fish-fauna, and its comparison with that of the Arctic regions, is one of the most instructive portions of zoogeography. The abundance of fish-life appears to decrease in the same proportion towards both Poles. The forms peculiar to the Antarctic are analogous to those of the north; thus the Cottoids of the north are represented by the *Nototheniæ*, *Chœnichthys*, &c., of the south, the Salmonoids by the Haplochitonidæ; yet there is no such relation between the representative forms as might be considered to be genetic. The resemblance is rather an external one, indicated by the general form of the body, structure and development of the fins, presence of an adipose fin, &c. Besides those fishes which are peculiar to the Antarctic some other forms well developed in the north, but nearly or entirely disappearing between the tropics, reappear, as *Sebastes*, *Agonus*, *Spinax*, *Myxine*, differing but little from their northern congeners.—(GÜNTHER, *Zool. Chall. Exp.*, part 6, p. 14.)

[2] It may be of interest to insert here some general remarks of Dr VON WILLEMOES-SUHM on the results of the shallow-water dredgings and trawlings taken at Kerguelen by the Challenger in the month of January 1874, extracted from the Challenger Report, Summary of Results, pp. 478–480, as he refers to a few animals not included in our

As in the case of the preceding lists, the great majority of the 533 species enumerated in the above list were each taken only at one of the four Stations or localities, but a certain number occurred at more than one of these localities.

LIST IV*a*.

We give here a list of such species, indicating in brackets the number of Stations or localities at which each species was found. It will be noticed that out of the 102

list, the specimens of which probably did not reach the hands of the specialists who described the Challenger collections: —"The prevailing animals in the shallow-water dredging on January 17 were Echinodermata, next to which Sponges and Polyzoa were represented by a considerable number of genera and species. There were also a large simple Ascidian and a small composite one; simple Ascidians were apparently far from numerous here, nor, indeed, were hey abundant at any place where we have dredged in shallow water,—an interesting fact, if confirmed as we go on. Annelids were represented especially by numerous Aphroditaceans, belonging probably to the genera *Aphrodita* and *Hermione*, and a few Terebellids; there were also two Nemerteans, one a particularly large one with immense mouth. The almost total absence of higher Crustacea in the shallow-water fauna of these Antarctic islands is very astonishing. Near Marion Island a caridid shrimp was taken in great numbers, while here at Kerguelen not a single Decapod was found. An Amphipod, the *Gammarus* which in water takes the place of flies on land, was very common. For Isopods this seemed to be a favourite territory, *Serolis* being probably the most numerous in specimens and species, though small Sphæromidæ were not uncommon, and several specimens of a spiny *Arcturus* were taken; most of these Isopods had eggs or young in their breeding pouches. A species of *Tanais* obtained to-day was very interesting on account of its method of reproduction; it had no breeding lamellæ, as in all Isopods hitherto known, but instead two sacs at the base of the fifth pair of legs, which contained the young ones, reminding one very much of the well-known sacs at the base of the last pair of feet in Copepods. They were in every way similar, but here rounded and not elongated, about 2½ inches in diameter, and containing each about twenty embryos, which evidently remain there, as they do in the breeding pouches of other species, until they have attained their full development. Among the Molluscs there was a large white Nudibranch and a few Gasteropoda and Lamellibranchiata, all indicating great uniformity in the Molluscan fauna of the place. On January 20, the dredge brought up some specimens of *Siphonostomum*, a genus very common in the north and in the Mediterranean, which has a great resemblance to the northern species. These worms have, besides two long tentacles, a quantity of branchial filaments and papillæ surrounding the mouth; at the first segment there are also very strong and long setæ standing erect in front, and having a peculiar structure; in the skin are many glands that exude a slimy secretion, by which they are generally surrounded. On January 21, the dredge brought up large specimens of *Serolis*, and in the trawl were great quantities of a *Caprella*, the male of which is very much elongated, and has enormously long anterior claws; the female had eggs in its pouch. On January 29, the dredge brought up many Echinoderms, a singular round simple Ascidian, and among the worms *Clymenia* and *Terebella*, along with *Dentalium* and other Molluscs. The trawl procured in the afternoon a prodigious quantity of animals, including specimens of a large *Rossella*, a smaller siliceous Sponge, and a stalked one; small Planarians and Nemerteans; many Annelids, among which were large quantities of *Aphrodita* and *Siphonostomum*, and also a small *Sipunculus*; quantities of Polyzoa, also simple and composite Ascidians; among Crustacea, an Ostracode belonging to the Cypridinidæ, some of the big members of which seem to inhabit deeper water, many Pycnogonids, among which were a small *Nymphon*, a large red *Nymphon*, and *Pycnogonum* (several of these spiders were overgrown by an *Alcyonium*, which much enlarged their appearance), two female specimens of *Nebalia*, differing only slightly from the Mediterranean *Nebalia geoffroyi*, several male and female specimens of a Petalophthalmid, an inch long, apparently belonging to my genus *Crozetia* [=*Amblyops*, Sars], established on a much larger species from deep water (these specimens with their larvæ show that the animals undergo the *Mysis*-development, and that the genus is more nearly allied to the ordinary *Mysis* than to the deep-sea Petalophthalmids); among the Isopods were quantities of *Serolis*, old and young in all stages of development, a few specimens of the *Tanais* taken on the 17th, and males and ovigerous females of *Praniza* (*Anceus*), showing hardly any differences from the species studied by Dohrn at Plymouth and described by Spence Bate in his British Sessile-Eyed Crustacea; Amphipods were represented by several small species, and a large one distinguished by a bright-red process at the front of the carapace, containing, under a simple chitinous layer, pigment arranged in hexagons (I could discover no trace of bodies entitling them to be called eyes, of which they are very probably the rudiments); of Cumacea a little *Cuma* was very abundant, in the males of which the second antennæ seem to remain in the same state of development as in the female. Except the Schizopod already mentioned, not a single member of the higher stalk-eyed Crustacea was taken, and probably no others exist here in shallow water. Three specimens of a *Raia*, not mentioned in Günther's Catalogue of Fishes, were also obtained."

species, only 4 species were procured at all the four localities, while 23 species occurred each at three of the Stations, and the remaining 75 species each at two of the Stations (looking upon the many dredgings taken in the vicinity of Kerguelen and of Marion Islands as constituting each one Station).

Amphilectus pilosus (2).
Stylocordyla stipitata (2).
Tetilla grandis (2).
Rossella antarctica (3).
Leuconia fruticosa (2).
Promachocrinus kerguelensis (2).
Asterias meridionalis (3).
„ (*Smilasterias*) *scalprifera* (2).
Bathybiaster loripes (2).
Cribrella simplex (2).
Gnathaster elongatus (4).
„ *meridionalis* (4).
Labidiaster annulatus (3).
Leptoptychaster kerguelenensis (2).
Perknaster fuscus (2).
Porania spiculata (2).
Amphiura studeri (3).
Gorgonocephalus pourtalesii (3).
Ophiacantha imago (3).
„ *vivipara* (3).
Ophioconis antarctica (2).
Ophiocten amitinum (2).
Ophioglypha deshayesi (3).
„ *hexactis* (2).
Echinus margaritaceus (3).
Goniocidaris canaliculata (3).
Hemiaster cavernosus (2).
Chirodota contorta (2).
Cucumaria lævigata (2).
„ *serrata* (3).
Psolus ephippifer (4).
„ *incertus* (3).
Amphiporus marioni (2).
Cerebratulus corrugatus (2).
Lætmonice producta (3).
Lagisca antarctica (2).
Neottis antarctica (4).
Nephthys trissophyllus (2).
Nereis (*Platynereis*) *eatoni* (2).
Serpula narconensis (3).
Bairdia villosa (2).
Cythere foveolata (2).
„ *kerguelenensis* (2).
„ *subrufa* (2).
„ *wyville-thomsoni* (3).
Cytheropteron assimile (2).
Macrocypris maculata (2).
Pseudocythere caudata (2).
Sclerochilus contortus (2).
Xestoleberis depressa (2).
„ *setigera* (3).
Eusirus longipes (2).
Iphimedia pacifica (2).
Liljeborgia consanguinea (2).
Œdiceroides rostrata (2).
Phoxocephalus kergueleni (2).
Arcturus furcatus (2).
Astacilla marionensis (2).
Serolis septemcarinata (2).
Halicarcinus planatus (2).
Cardita astartoides (2)
Davila (?) *umbonata* (2).
Kellia nuculina (2).
Lima (*Limatula*) *pygmæa* (2).
Modiolarca trapezina (2).
Mytilus meridionalis (2).
Saxicava arctica (2).
Thracia meridionalis (2).
Cancellaria (*Admete*) *specularis* (2).
Natica fartilis (3).
Neobuccinum eatoni (2).
„ *vestitum* (2).
Patella kerguelensis (2).
Pleurotoma (*Thesbia*) *translucida* (2).
„ (*Typhlomangelia*) *fluctuosa* (2).
Provocator pulcher (2).
Rissoa (*Setia*) *principis* (2).
Struthiolaria mirabilis (2).
Trochus (*Margarita*) *charopus* (2).
„ (*Photinula*) *expansus* (2).
Trophon declinans (2).
Turritella austrina (2).
Bicellaria pectogemma (3).
Bugula longissima (2).
Caberea darwinii (2)
Carbasea ovoidea (2).
Cellepora bicornis (3).
Cellularia quadrata (2).
Cribrilina philomela (2).
Idmonea marionensis (2).
„ *milneana* (2).
Membranipora galeata (3).
Menipea flagellifera (2).
Myriozoum marionense (2).

Onchopora sinclairii (3).
Pustulopora proboscidea (2).
Salicornaria clavata (3).
„ *malvinensis* (2).
Smittia marionensis (2).
Vincularia gothica (2).
Waldheimia kerguelenensis (3).
Colella pedunculata (2).

The preceding list of species from the shallow waters of the Kerguelen Region (List IV.) shows that in the vicinity of these islands of the Southern Indian Ocean, in depths not exceeding 150 fathoms, the Challenger procured representatives of 533 species and varieties of Metazoa belonging to about 325 genera. The proportion of the number of genera relatively to the number of species is here as 1 to 1·64.

An examination of the list shows that 25 of the species have received no specific names, and there are besides 11 varieties enumerated as well as the species to which they belong; in addition the list includes 2 species of internal parasites (Entozoa), the distribution of which cannot be discussed along with the other marine organisms. Making these deductions there remain 495 distinct fully-described species the distribution of which may be discussed in detail.

These 495 species may be divided into those that are known only from these dredgings in the neighbourhood of the islands in the Southern Indian Ocean, and those that extend into other regions of the ocean.

a. *Species limited to the shallow-water area of the Kerguelen Region.*

In the first place, we find that there are 326 species (or 61 per cent. of the total number of species and varieties found in these dredgings) which, so far as we know up to the present time, are confined to the area represented by these dredgings.[1] These 326 species are distinguished by an asterisk in the list, and very little can be said about them beyond the fact that they are known only from the area represented by these dredgings and from depths not exceeding 150 fathoms.

LIST IV *b*.

We here enumerate the 52 species found at more than one of these Stations or localities, indicating in brackets the number of Stations at which each species was found. It will be observed that only 2 species occurred at all the four localities, while 7 species were each found at three of the Stations, and the remaining 43 species each at two Stations.

[1] Nine of these species have subsequently been recorded from South Georgia, viz., *Asterias meridionalis*, *Ophioglypha hexactis*, *Lagisca antarctica* [=*Harmothoë vesiculosa*], *Nereis kerguelensis*, *Nymphon brevicaudatum*, *Litorina* [=*Pellilitorina*] *setosa*, *Hemiarthrum setulosum*, *Chorizocormus reticulatus*, and *Colella concreta*; there are besides other eight species with a wider distribution (as will be noticed in the succeeding notes) recorded from South Georgia, viz., *Porania antarctica*, *Hemiaster cavernosus*, *Serolis septemcarinata*, *Modiolarca trapezina*, *Hydrobia* [=*Lævilitorina*] *caliginosa*, *Trochus* (*Photinula*) *expansus*, *Colella pedunculata*, and *Harpagifer bispinis*, making altogether seventeen species in our list found since at South Georgia (see PFEFFER, "Die Niedere Thierwelt des antarktischen Ufergebietes," *Ergebnisse der deutschen Polar-Expeditionen*).

Amphilectus pilosus (2).
Tetilla grandis (2).
Promachocrinus kerguelensis (2).
Asterias meridionalis (3).
„ (*Smilasterias*) *scalprifera* (2).
Gnathaster elongatus (4).
„ *meridionalis* (4).
Leptoptychaster kerguelenensis (2).
Perknaster fuscus (2).
Ophiacantha imago (3).
Ophioconis antarctica (2).
Ophioglypha deshayesi (3).
„ *hexactis* (2).
Cucumaria lævigata (2).
Psolus incertus (3).
Amphiporus marioni (2).
Cerebratulus corrugatus (2).
Lagisca antarctica (2).
Nephthys trissophyllus (2).
Cythere foveolata (2).
„ *subrufa* (2).
Cytheropteron assimile (2).
Xestoleberis setigera (3).
Iphimedia pacifica (2).
Liljeborgia consanguinea (2).
Œdiceroides rostrata (2).
Phoxocephalus kergueleni (2).
Astacilla marionensis (2).
Cardita astartoides (2).
Davila (?) *umbonata* (2).
Kellia nuculina (2).
Mytilus meridionalis (2).
Thracia meridionalis (2).
Cancellaria (*Admete*) *specularis* (2).
Natica fartilis (3).
Neobuccinum eatoni (2).
Neobuccinum vestitum (2).
Patella kerguelensis (2).
Pleurotoma (*Thesbia*) *translucida* (2).
„ (*Typhlomangelia*) *fluctuosa* (2).
Provocator pulcher (2).
Rissoa (*Setia*) *principis* (2).
Struthiolaria mirabilis (2).
Trochus (*Margarita*) *charopus* (2).
„ (*Photinula*) *expansus* (2).
Trophon declinans (2).
Turritella austrina (2).
Bugula longissima (2).
Cellularia quadrata (2).
Smittia marionensis (2).
Vincularia gothica (2).
Waldheimia kerguelenensis (3).

b. *Species extending outside the shallow-water area of the Kerguelen Region.*

We come now to consider those species which have a wider distribution, and extend into other regions of the ocean outside the area represented by these dredgings. The number of such species is 169 (or 32 per cent. of the total number of species and varieties found in these dredgings), and they may be divided into groups according to their distribution in the tropical and extra-tropical regions of the ocean. Thus we find that of these 169 species,

100 species (or 60 per cent.) are known to occur in other regions south of the southern tropic (see List IV*c.*);

33 species (or 19 per cent.) are known to occur in regions both south and north of the tropics, but not in the intervening tropical zone (see List IV*d.*);

20 species (or 12 per cent.) are known to occur in regions both south of and within the tropics, but not to the north of the northern tropic (see List IV*e.*); and

16 species (or 9 per cent.) are known to occur in regions both south of, within, and north of the tropics, and some of them may be regarded as cosmopolitan, or almost cosmopolitan (see List IV*f.*).

We may now proceed to discuss in some detail the distribution of these 169 species, according to the groups given above, indicating briefly the geographical and bathymetrical distribution of each species outside the area represented by these dredgings.

LIST IV*c*.

In the first place we give a list of the 100 species which are known to occur outside the Kerguelen shallow-water area in regions south of the southern tropic. From the distributional notes accompanying each species it will be observed that 41 of the species descend into depths greater than 150 fathoms, of which 11 species reach deep water over 1000 fathoms.

Desmacidon (?) *ramosa*—Near the Cape, 150 fathoms.
Gellius carduus—Near the Crozets, 210 to 550 fathoms; Magellan Strait, 245 fathoms (var.).
„ *glacialis*—Near the Cape, 150 fathoms.
Latrunculia apicalis—Near River Plate, 600 fathoms.
Myxilla mariana—Off South-West Patagonia, depth (?).
Suberites antarcticus—Antarctic (lat. 74½° S.), 206 fathoms.
„ *caminatus*—Near River Plate, 600 fathoms.
Rossella antarctica—Antarctic (lat. 74°–77° S., long. 175° W.), 206–300 fathoms; near River Plate, 600 fms.
Leuconia fruticosa—[Recorded from ?].
Lophogorgia flammea—Cape of Good Hope, depth (?); [the Challenger specimen was without label, but is supposed to have come either from Simon's Bay or Prince Edward Island].
Thouarella variabilis—Near Crozets, 310 fathoms.
Halcampa clavus—[Recorded from ?].
Leiotealia nymphœa—Near Valparaiso, depth (?).
Halecium flexile—Magellan Strait, 9 fathoms.
Bathybiaster loripes—Magellan Strait, 245 fathoms.
Cribrella simplex—Near Crozets, 310 fathoms; near Tristan da Cunha, 90 to 150 fathoms.
Crossaster penicillatus—Near Tristan da Cunha, 110 fathoms.
Porania antarctica—Southern Ocean, 1600 fathoms; South Georgia, depth (?).
Amphiura antarctica—Magellan Strait, depth (?).
„ *studeri*—Near Marion Island, 310 fathoms.
Astrotoma agassizii—Near Crozets, 210 fathoms; Magellan Strait, 40 to 175 fathoms; between Magellan Strait and Falklands, 55 fathoms.
Gorgonocephalus pourtalesii—Magellan Strait, 140 and 175 fathoms; between Magellan Strait and Falkland Islands, 55 fathoms; East Patagonia, depth (?).
Ophiacantha vivipara—Falkland Islands, 70 fathoms; between Falklands and Magellan Strait, 55 fathoms; near River Plate, 600 fathoms.
Ophiocten amitinum—Southern Ocean, 1260, 1375, and 1950 fathoms.
Echinus magellanicus—Southern Ocean, 1600 fathoms; Magellan Strait, 9 to 175 fathoms; Falkland Islands, 12 fathoms; Patagonia, Chili, Cape, Australia, New Zealand.
„ *margaritaceus*—Magellan Strait, 175 and 245 fathoms; New Zealand (shore).
Hemiaster cavernosus—Magellan Strait, 400 fathoms; Patagonia, Chili, River Plate (shore); South Georgia.
Schizaster moseleyi—Southern Ocean, 1375 fathoms; Magellan Strait, 40 to 400 fathoms.
Chirodota contorta—Falkland Islands, 70 fathoms; between Magellan Strait and Falklands, 55 fathoms.
Cucumaria serrata—Near Crozets, 550 fathoms.
Pseudostichopus mollis—Magellan Strait, 140 and 245 fathoms.
Psolus ephippifer—Near Marion Island, 310 fathoms.
Eulagisca corrientis—Near River Plate, 600 fathoms.
Eunice magellanica—Magellan Strait, 175 and 245 fathoms.
Hermadion kerguelensis—Falkland Islands, 5 to 10 fathoms.
Lagisca magellanica—Near Marion Island, 310 fathoms (var.); Magellan Strait, 175 and 400 fathoms.
Neottis antarctica—Between Magellan Strait and Falkland Islands, 55 fathoms.
Phyllocomus crocea—Antarctic, between Crozets and Kerguelen, depth (?).

Serpula narconensis—Magellan Strait, 175 fathoms; Narçon Island, depth (?).
Terebella (*Lanice*) *flabellum*—South-East Australia, 150 fathoms; Narçon Island, depth (?).
Argillœcia eburnea—Near Rio de la Plata, 1900 fathoms.
Bairdia villosa—Tristan da Cunha, 100 to 150 fathoms; Bass Strait, 38 fathoms.
Cythere kerguelenensis—Bass Strait, 38 fathoms; Port Jackson, 2 to 10 fathoms.
„ *normani*—South-East Pacific, 1825 fathoms. [Recorded from ?].
„ *polytrema*—Known outside this area only as a fossil from Antwerp Crag.
Cytheropteron fenestratum—South Atlantic, near Tristan da Cunha, 1425 fathoms.
Macrocypris tumida—Wellington Harbour, New Zealand, tow-net at trawl.
Atyloides australis—Port Jackson, depth (?).
Euthemisto thomsoni—Antarctic, on several occasions at the surface.
Arcturus furcatus—Southern Ocean, 1675 fathoms.
Cymodocea darwini—Patagonia, depth (?).
Jæra pubescens—Patagonia, depth (?).
Neasellus kerguelenensis—Near River Plate, 600 fathoms.
Serolis cornuta—Crozets, depth (?).
„ *latifrons*—Near Crozets, 210 fathoms; Auckland Islands, depth (?).
„ *septemcarinata*—Crozets, depth (?); South Georgia.
Euphausia murrayi—Southern Ocean, surface.
Pseudomma sarsii—Southern Ocean, 1675 fathoms.
Nauticaris marionis—Falkland Islands, 12 fathoms.
Parapagurus dimorphus—Tristan da Cunha, 110 fathoms; Cape, 150 fathoms; Magellan Strait, 245 fathoms.
Halicarcinus planatus—Falkland Islands, 4 fathoms; New Zealand, depth (?).
Colossendeis megalonyx—Falkland Islands, 70 fathoms; between Falklands and Magellan Strait, 55 fathoms.
Anatina elliptica—New South Shetlands, depth (?)
Astarte magellanica—Magellan Strait, depth (?).
Lima (*Limatula*) *pygmœa*—South Patagonia, depth (?).
Modiolarca trapezina—Magellan Strait, 245 fathoms; Falkland Islands, 12 fathoms; South Georgia.
Hydrobia caliginosa—Tierra del Fuego, depth (?); South Georgia.
Patella fuegiensis—Tierra del Fuego and Falklands, depth (?).
Pleurotoma (*Surcula*) *staminea*—Southern Ocean, 1375 fathoms.
Triton (*Lagena*) *magellanicus*—Magellan Strait, 40 fathoms; Cape Horn, depth (?).
Trochus (*Photinula*) *expansus*—Falkland Islands, 5 to 12 fathoms (and from crop of duck); Magellan Strait, depth (?); South Georgia.
Trophon geversianus—Falkland Islands, 12 fathoms; Magellan Strait, depth (?).
Bicellaria pectogemma—[Recorded from ?].
Carbasea ovoidea—Magellan Strait, 9 and 175 fathoms; Falkland Islands, 12 fathoms; Patagonia, depth (?).
Cellepora albirostris—[Recorded from ?]
„ *bicornis*—Falkland Islands, 70 fathoms; between Falklands and Magellan Strait, 55 fathoms.
„ *eatonensis*—Magellan Strait, 175 fathoms; Falklands, 5 to 12 fathoms.
„ *pustulata*—New Zealand, 150 fathoms.
Chorizopora hyalina—Tristan da Cunha, 75 to 90 fathoms; Falkland Islands, 12 fathoms.
Cribrilina philomela—Curtis Island, depth (?).
Diachoris inermis—New Zealand and Magellan Strait, depth (?).
Flustramorpha marginata—Near Cape, 150 fathoms; South Africa, depth (?).
Idmonea australis—Port Jackson, 30 to 35 fathoms; Australia, depth (?).
Menipea benemunita—Magellan Strait, 175 fathoms; between Magellan Strait and Falklands, 55 and 70 fathoms; Falkland Islands, 5 to 12 fathoms.
„ *flagellifera*—Between Magellan Strait and Falklands, 55 and 70 fathoms.
„ *marionensis*—Near the Cape, 150 fathoms.
Mucronella tricuspis—Simon's Bay; Bass Strait, 38 fathoms; Falklands, 5 to 12 fathoms; South America, depth (?).

Mucronella ventricosa—Near Crozets, 210 fathoms.
Myriozoum marionense—Near Crozets, 210 to 550 fathoms.
Onchopora sinclairii—Southern Ocean, 1950 fathoms; Marion Island, Australia, and New Zealand, depth (?).
Salicornaria clavata—Bass Strait, 28 fathoms; Port Jackson, 35 fathoms; Magellan Strait, 45 fathoms.
„ *variabilis*—Magellan Strait, 45 fathoms; near Falklands, 70 fathoms.
Schizoporella marsupifera—New Zealand, 150 fathoms.
„ *triangula*—Bass Strait, 28 fathoms.
Rhynchonella nigricans—New Zealand and Chatham Islands, depth (?); fossil (?), Tasmania.
Terebratella dorsata—Chili to Magellan Strait, depth (?).
Colella pedunculata—Between Magellan Strait and Falklands, 55 and 70 fathoms; Falkland Islands, 12 fathoms; Magellan Strait, South Georgia and Australia, depth (?).
Chœnichthys rhinoceratus—[Recorded from ?].
Harpagifer bispinis—Cape Horn and Falkland Islands, depth (?); South Georgia.
Notothenia cyaneobrancha—[Recorded from ?].

LIST IV *d*.

In the second place we give a list of the 33 species which are known to occur in regions both south and north of the tropics, but which have not hitherto been recorded from the intervening tropical zone. From the distributional notes accompanying each species, it will be observed that 13 of the species descend into depths greater than 150 fathoms, of which 9 species reach deep water over 1000 fathoms.

Eudendrium rameum—British Seas, depth (?).
Obelia geniculata—Falkland Islands, 5 to 12 fathoms; Arctic, North Atlantic and North Pacific, depth (?).
Ophiocten sericeum—Off coast of Massachusetts, depth (?).
Drepanophorus serraticollis—Bass Strait, 38 fathoms; Mediterranean, depth (?).
Eunice œrstedi—Off east coast of United States, 1240 fathoms; off Nova Scotia, 85 fathoms.
Terebellides strœmi—Near Nova Scotia, 1340 fathoms; Europe and America, depth (?).
Cythere suhmi—North-West Pacific, 2300 fathoms.
Paradoxostoma abbreviatum—European Seas, depth (?).
Pseudocythere caudata—Near Rio de la Plata, 1900 fathoms; European Seas, depth (?).
Sclerochilus contortus—Wellington Harbour, New Zealand (tow-net at trawl); Arctic and European Seas, depth (?); fossil.
Xestoleberis depressa—Arctic, European and American Seas, depth (?); fossil.
Eusirus longipes—Northern Seas, depth (?).
Podocerus falcatus—Near Cape, from screw; South Atlantic, near River Plate, tow-net; British Seas.
Typhlotanais kerguelenensis—Mid North Pacific, 2050 fathoms.
Kellia suborbicularis—European Seas southward to Canaries, depth (?).
Homalogyra atomus—European seas to Madeira, depth (?); fossil.
Natica (*Lunatia*) *grönlandica*—Arctic, European, and American Seas, 2 to 1290 fathoms; fossil.
Odostomia rissoïdes—European Seas, 0 to 777 fathoms; fossil.
Puncturella noachina—Near Marion Island, 310 fathoms; Magellan Strait, 9 to 15 fathoms; Arctic, North Atlantic and North Pacific, 5 to 1095 fathoms; fossil.
Cribrilina monoceros—Port Jackson, 35 fathoms; Magellan Strait, 175 fathoms; between Magellan Strait and Falkland Islands, 55 fathoms; Falkland Islands, 12 fathoms; near River Plate, 600 fathoms; mid North Pacific, 3125 fathoms.
Crisia eburnea—Arctic and European Seas to Madeira, depth (?).
Diachoris magellanica—Port Jackson, 2 to 10 fathoms; Falklands, 5 to 12 fathoms; Magellan Strait, Australia, New Zealand, Adriatic, depth (?).

Escharoides verruculata—Gulf of Mexico, West of Tortugas, depth (?).
Hornera violacea—Arctic, Northern and British Seas, depth (?).
Idmonea atlantica—Tristan da Cunha, 100 to 150 fathoms; Simon's Bay, 18 fathoms; off Nova Scotia, 85 fathoms; Arctic, North Atlantic, Mediterranean, Florida, depth (?); fossil.
„ *marionensis*—Southern Ocean, 1600 fathoms; near River Plate, 600 fathoms; Australia and Naples Bay, Mediterranean, depth (?); fossil.
„ *milneana*—North Atlantic, off Azores, 450 fathoms; Australia, Falklands, Tierra del Fuego, Patagonia, Chonos Archipelago, 10 to 30 fathoms (?).
Membranipora crassimarginata—Tristan, 110 to 150 fathoms; Bass Strait, 38 fathoms; Madeira, depth (?); Gulf of Florida, 13 to 60 fathoms.
„ *galeata*—Simon's Bay; near Rio de la Plata, 600 fathoms; North Atlantic, off Azores, 450 fathoms. [Recorded from ?].
Pustulopora deflexa—British Seas, Mediterranean, Gulf of Florida, depth (?).
„ *proboscidea*—Australia, North Atlantic, Mediterranean, Gulf of Florida, depth (?).
„ *proboscidioides*—Gulf of Florida, depth (?).
Platydia anomioides—Mediterranean and North Atlantic, 40 to 600 fathoms; Florida Reefs, depth (?); fossil.

LIST IV *e*.

In the third place we give a list of the 20 species which are known to occur in regions both south of and within the tropics, but which have not hitherto been recorded from regions north of the tropic of Cancer. From the distributional notes accompanying each species it will be observed that 10 of the species descend into depths greater than 150 fathoms, of which only 1 species reaches deep water over 1000 fathoms.

Petrosia similis—Near the Cape, 150 fathoms; between Magellan Strait and Falklands, 70 fathoms (var.); Philippines, 18 fathoms (var.).
Labidiaster annulatus—Near Arrou Islands, 800 fathoms.
Porania spiculata—Near Arrou Islands, 800 fathoms.
Goniocidaris canaliculata—Southern Ocean, 1600 to 1975 fathoms; between Magellan Strait and Falkland Islands, 55 fathoms; Falklands, 5 to 12 fathoms; Natal, Zanzibar and Australia, depth (?).
Nereis (*Platynereis*) *eatoni*—Falkland Islands, 5 to 10 fathoms; Fernando Noronha, 25 fathoms.
Bythocypris reniformis—Bass Strait, 38 fathoms; off Brazil, 350 and 675 fathoms; West Indies, 390 fathoms.
Cythere audei—Ascension, 7 fathoms; Mauritius and Colon-Aspinwall, depth (?).
„ *wyville-thomsoni*—Torres Strait, 155 fathoms.
Cytheropteron (?) *angustatum*—Torres Strait, 155 fathoms.
Macrocypris decora—West Indies, 390 fathoms; off Brazil, 350 fathoms; Admiralty Islands, 16 to 25 fathoms; Australia and Batavia, depth (?).
„ *maculata*—Simon's Bay, 15 to 20 fathoms; Bass Strait, 38 fathoms; Amboina, 15 to 20 fathoms.
Campylonotus capensis—Off Brazil, 350 fathoms.
Mytilus magellanicus—Falkland Islands, 12 fathoms; Fiji, New Zealand, depth (?).
Fusus (*Euthria*) *fuscatus*—Falkland Islands, 4 to 12 fathoms; Peru, depth (?),
Caberea darwinii—Tristan da Cunha, 110 to 150 fathoms; near Cape, 150 fathoms; near Crozets, 210 to 550 fathoms; Magellan Strait, New Zealand and Cumberland Island, depth (?).
Crisia holdsworthii—Ceylon, depth (?).
Valicornaria malvinensis—Magellan Strait, 45 fathoms; Falkland Islands, 5 to 10 fathoms; New Hebrides 70 fathoms; South Patagonia, depth (?); fossil.
Smittia jacobensis—Cape Verde Islands, 100 to 120 fathoms.
Terebratula uva—S.E. Australia, 150 fathoms; off River Plate, 600 fathoms; Falklands and Guatemala, depth (?).
Aplidium fumigatum—Philippines, reefs.

LIST IV*f*.

In the fourth place we give a list of the 16 widely-distributed species which are known to occur both in tropical and extra-tropical regions. From the distributional notes accompanying each species it will be observed that 13 of the species descend into depths greater that 150 fathoms, of which 7 species reach deep water over 1000 fathoms.

Halichondria panicea—Japan, shore; Torres Strait, Ceylon, British Seas, and Atlantic, depth (?).
Stylocordyla stipitata—Southern Ocean, 1600 fathoms; Bahia, 7 to 20 fathoms; Nova Scotia, 85 fathoms; British Seas, and Grenada, depth (?).
Lætmonice producta—Mid South Atlantic, 1900 fathoms; Southern Ocean, 1375 to 1950 fathoms; near New Zealand, 700 fathoms; near Torres Strait, 1400 fathoms; Nova Scotia, 85 fathoms; Mid North Atlantic, 1675 fathoms; Mid North Pacific, 2300 and 2900 fathoms.
Scolecolepis cirrata—West Indies, 450 fathoms; both sides of North Atlantic, 29 to 584 fathoms.
Bairdia victrix—Bass Strait, 38 fathoms; near Sydney, 410 fathoms; Mid South Atlantic, 1425 fathoms; off Brazil, 350 and 675 fathoms; off Azores, 450 and 900 fathoms; Colon-Aspinwall and Cuba, depth (?).
Cythere dictyon—Cosmopolitan, 37 to 2750 fathoms.
Krithe bartonensis—Near Arrou Islands, 580 fathoms; European seas, depth (?); fossil.
„ *producta*—Widely distributed: South, tropical and North Atlantic, Magellan Strait, South and tropical Pacific, and Southern Ocean, 50 to 1825 fathoms.
Polycope orbicularis—Near Cape, 150 fathoms; Torres Strait, 155 fathoms; Vigo Bay, 11 fathoms; Arctic and North Atlantic, depth (?); fossil.
Xestoleberis curta—Port Jackson, 2 to 10 fathoms; South-East Pacific, 1375 fathoms; Torres Strait, 6 fathoms; Sandwich Islands, 40 fathoms; off Bermuda, 435 fathoms; West Indies, depth (?).
Saxicava arctica—Tristan da Cunha, 100 to 150 fathoms; Cape, 98 and 150 fathoms; Port Jackson, 2 to 10 fathoms; Magellan Strait, 245 fathoms; between Magellan Strait and Falklands, 55 fathoms; off Azores, 450 fathoms; a cosmopolitan species; fossil.
Dentalium entalis—Ascension, 420 fathoms; North Atlantic, off Portugal, Canaries, Azores, and Nova Scotia, 85 to 620 fathoms; Arctic, North Atlantic, Gulf of Mexico, and Mediterranean, down to 1750 fathoms; fossil.
Scissurella crispata—West Indies, 390 fathoms; Arctic, North Atlantic, and Mediterranean, 4 to 790 fathoms; fossil.
Hippothoa flagellum—Cosmopolitan, depth (?); fossil.
Nellia oculata—Near Crozets, 210 to 550 fathoms; Torres Strait, 28 and 49 fathoms; Philippines, 18 fathoms; Bahia, 10 to 40 fathoms; Indian Ocean, Gulf of Florida, depth (?).
Terebratulina caput-serpentis—Near Cape, 150 fathoms; Nova Scotia, 51 and 85 fathoms; West Indies, Arctic, North Atlantic, North Pacific, and Australia, depth (?).

We may now summarise the distribution of these 169 species, which extend into other regions of the ocean outside the Kerguelen shallow-water area, as follows:—

Bathymetrical Distribution.—It appears that of these 169 species, 92 species are apparently not found deeper than the 150 fathoms line, the remaining 77 species are found on both sides of the 150 fathoms line, of which 28 species cross the 1000 fathoms line into deep water.

LIST IV *g*.

Eight of the species are recorded from the shore, and there are also 9 species recorded from the shore which are known only from the area under consideration; it may be of interest to give here a list of these 17 shore species, indicating the 9 species confined to this area by an asterisk *.

Halichondria panicea.
Echinus margaritaceus.
Hemiaster cavernosus.
Jæra pubescens.
Halicarcinus planatus.
Mytilus magellanicus.
**Eatoniella caliginosa.*
Hydrobia caliginosa.
**Neobuccinum eatoni.*
Patella fuegiensis.
* „ *kerguelensis.*
**Rissoa* (*Setia*) *australis.*
* „ („) *principis.*
* „ („) *sinapi.*
**Scissurella obliqua.*
**Skenea subcanaliculata.*
**Hemiarthrum setulosum.*

These are all shallow-water species unknown deeper than 150 fathoms, except *Echinus margaritaceus* and *Hemiaster cavernosus*, which descend to 245 and 400 fathoms respectively.

Geographical Distribution.—Of the 169 species we find that :—

62 species are represented in the Magellan Strait area (including Falklands and Fuegia).
45 „ „ „ North Atlantic.
44 „ „ „ South Pacific (including Bass Strait).
40 „ „ „ South Atlantic.
29 „ „ among the islands of the Southern Ocean (including South Georgia).
22 „ „ in the Tropical Pacific.
18 „ „ „ Tropical Atlantic.
14 „ „ „ deep-water area of the Kerguelen Region.
13 „ „ „ Arctic Ocean.
11 „ „ „ North Pacific.
5 „ „ „ Indian Ocean.
5 „ „ „ Antarctic regions (surface and moderate depths).

In addition there are 6 species the habitats of which outside this area are unknown, and 1 species (*Cythere polytrema*) known only as a fossil outside this area.

LIST IV *h*.

The following eighteen species have been recorded as occurring in the fossil condition, and are therefore of interest :—

Cythere polytrema.
Krithe bartonensis.
Polycope orbicularis.
Sclerochilus contortus.
Xestoleberis depressa.
Saxicava arctica.
Dentalium entalis.
Homalogyra atomus.
Natica (Lunatia) grönlandica.
Odostomia rissoïdes.
Puncturella noachina.
Scissurella crispata.
Hippothoa flagellum.
Idmonea atlantica.
„ *marionensis.*
Salicornaria malvinensis.
Platydia anomioides.
Rhynchonella nigricans.

LIST IV *i*.

Turning now our attention to the 325 genera represented at these shallow-water Stations, we find that the following 25 genera (or 8 per cent.) are known up to the present time only from these Stations. It will be observed that the great majority (20) of the genera each include only a single species taken at a single Station; 1 genus, however, with a single species was taken at two distinct Stations; 3 genera each contain 2 species taken at two Stations, and 1 genus contains 2 species, both taken at the same Station, as indicated in brackets after the name :—

Cinachyra	(1	species	taken	at	1	Station).	*Socarnoides*	(1	species	taken	at 1 Station).
Scytophorus	(1	„	1	„	)		*Sophrosyne*	(1	„	1	„)
Schizotricha	(2	„	2	„	)		*Astrurus*	(1	„	1	„)
Staurotheca	(1	„	1	„	)		*Paralamprops*	(1	„	1	„)
Perknaster	(2	„	2	„	)		*Provocator*	(1	„	2	„)
Salvatoria	(1	„	1	„	)		*Marseniopsis*	(2	„	2	„)
Acanthechinus	(1	„	1	„	)		*Ascopera*	(2	„	1	„)
Cardenio	(1	„	1	„	)		*Chorizocormus*	(1	„	1	„)
Cheirimedon	(1	„	1	„	)		*Morchellioides*	(1	„	1	„)
Dodecas	(1	„	1	„	)		*Tylobranchion*	(1	„	1	„)
Harpinioides	(1	„	1	„	)		*Murœnolepis*	(1	„	1	„)
Kerguelenia	(1	„	1	„	)		*Zanclorhynchus*	(1	„	1	„)
Protellopsis	(1	„	1	„	)						

In addition the two genera *Eulagisca* and *Neasellus*, each with a single species, are known apart from these dredgings only from near the Rio de la Plata, in 600 fathoms.

Gnathophausia gigas, Willemoes-Suhm. Taken by the Challenger in the North Atlantic and in the Kerguelen Region.

LIST V.

Metazoa recorded from the Kerguelen Region, from Sources other than the Challenger Expedition.

In order to complete our survey of the marine fauna of the Kerguelen Region we give here a list of species recorded from other sources[1] (British and American Transit of Venus Expeditions, "Gazelle" Expedition, &c.), excluding a number of unnamed species, the distribution of which cannot be discussed, as well as land and fresh-water species. Species already recorded in the preceding Challenger list (List IV.) are not repeated in this list, and where the nomenclature does not agree that adopted in the Challenger Report is indicated in square brackets.

Monaxonida[2]:

Halichondria [=*Suberites*] *carnosa*, Johnston. Recorded from Britain, Azores, Fernando Noronha, Port Jackson, and Vancouver's Island (?).

,, [=*Myxilla*] *plumosa*, Johnston. Recorded from Britain.

,, *sanguinea*, Johnston. Recorded from Britain.

Isodictya rosea, Bowerbank. Recorded from Britain.

[1] See "An account of the Petrological, Botanical, and Zoological Collections made in Kerguelen's Land and Rodriguez during the Transit of Venus Expeditions, carried out by order of Her Majesty's Government in the years 1874-75," *Philosophical Transactions*, vol. 168 (extra volume), 1879; J. H. Kidder, "Contributions to the Natural History of Kerguelen Island, made in connection with the United States Transit-of-Venus Expedition, 1874-75," *Bull. U.S. Nat. Mus.*, No. 3, 1876; Studer, "Über Echinodermen aus dem antarktischen Meere, gesammelt auf der Reise S.M.S. Gazelle um die Erde," *Monatsber. d. k. Akad. d. Wiss. Berlin*, 1876, pp. 452–463; Studer, *Ibid.*, 1878, pp. 542–546, 633, 661; Studer, "Die Fauna von Kerguelensland," *Archiv für Naturgeschichte*, Jahrg. xlv. Bd. i. pp. 104–141, 1879; Studer, "Uebersicht über die Ophiuriden, welche, während der Reise S.M.S. Gazelle um die Erde 1874–1876 gesammelt wurden," *Abhandl. d. k. Akad. d. Wiss. Berlin*, 1882, pp. 1–37; Studer, "Isopoden, gesammelt während der Reise S.M.S. Gazelle um die Erde 1874–76," *Ibid.*, 1883, pp. 1–28; Grube, "Annelidenausbeute von S.M.S. Gazelle," *Monatsber. d. k. Akad. d. Wiss. Berlin*, 1877, pp. 509–554; Crosse, "Faune malacologique des îles Kerguelen," *Journ. de Conchyliologie*, sér. 3, tom. xvii. p. 1, 1877.

[2] Of the Sponges collected at Kerguelen by the British Transit of Venus Expedition, H. J. Carter writes:—The collection of Sponges from Kerguelen Island is very limited in extent. So far as it goes, it may be said to present a European, and more especially a British facies. Half of the species at the fewest, may be picked up at any time on the beach of South Devon:—viz., *Isodictya rosea*, *Halichondria plumosa*, *H. carnosa*, and *H. sanguinea*. To these we might add a fifth species, *H. panicea*, for the Kerguelen variety differs from the normal British form only in the possession of spicules twice the size of the latter. Of the three species remaining *Thalysias* is common to the Mediterranean and the seas between the Americas; the *Ute* occurs on the N.W. coast of Spain and in the Mediterranean; and one only, the *Tethya*, is decidedly antarctic. This last was the only specimen obtained from a considerable depth; all of the others were either collected with the grapple within the Laminarian zone, or were the produce of shore-collecting between tide-marks or amidst the refuse of the beach. Probably more extended research would have brought to light divers of the many peculiar forms which abound in the Cape seas and in those of the southern part of Australia. In the course of my examination I have met with very few *Foraminifera*, no *Globigerina*, and no *coccoliths*.—(*Phil. Trans.*, vol. 168, p. 286.)

Carter refers some Sponges collected at Kerguelen by the British Transit of Venus Expedition to the species *Thalysias subtriangularis*, Duchassaing and Michelotti, and *Tethya antarctica*, Carter. Ridley and Dendy refer the first to their *Petrosia similis*, regarding it as distinct from the West Indian *Petrosia subtriangularis*, while Sollas refers the second to his *Tetilla grandis*, regarding it as distinct from *Tetilla antarctica* obtained by Ross' Antarctic Expedition in 206 and 300 fathoms in the neighbourhood of Victoria Land.

CALCAREA :

Ute [= *Sycon*] *capillosa*, Schmidt. Recorded from Vigo Bay and Mediterranean.

ALCYONARIA :

Clavularia rosea, Studer.
Isis [= *Primnoisis*] *antarctica*, Studer (see List III.).

ACTINIARIA :

Actinopsis rosea, Studer.
Bolocera kerguelensis, Studer.
Bunodes kerguelensis, Studer.
Edwardsia kerguelensis, Studer.
Halcampa purpurea, Studer.

HYDROIDA[1] :

Campanularia (?) *cylindrica*,[2] Allman. Recorded from Baffin's Bay.
Coryne conferta, Allman.
Halecium mutilum,[3] Allman.
Hydractinia antarctica, Studer.
Sertularella [= *Sertularia*] *lagena*, Allman.
,, [,,] *unilateralis*, Allman.
Sertularia polyzonias, Linné. A widely distributed species.
Tubularia (?) *kerguelensis*, Studer.

ASTEROIDEA[4] :

[1] PFEFFER records the widely distributed species, *Sertularia operculata*, Linné, from the Kerguelen region.—(*Ergebnisse der deutschen Polar-Expeditionen.*)

[2] The species which has been referred to *Campanularia* cannot be specifically distinguished from a hydroid obtained last autumn by H.M.S. "Valorous" in Baffin's Bay. It belongs to a common group of campanularian forms; but yet the fact of identical forms occurring in such widely separated localities, though under conditions probably very similar, is one of great interest and significance, more especially as the distribution can hardly be explained, as in certain other cases, by the transporting agency of ships' bottoms. . . . A form which cannot be distinguished specifically from this [*Campanularia* (?) *cylindrica*], has more recently been dredged by H.M.S. "Valorous" from 60 fathoms in Baffin's Bay.—(ALLMAN, *Phil. Trans.*, vol. 168, pp. 282, 284.)

[3] This species [*Halecium mutilum*], like *H. macrocephalum*, Allman, from the western part of the Gulf Stream, and *H. sessile*, Norman, from the Hebrides, is remarkable for the utter absence of the tubular prolongation of the lateral orifice of the internode which gives support to the hydranth in most of the species of *Halecium*.—(ALLMAN, *Phil. Trans.*, vol. 168, p. 283.)

[4] Of the Echinodermata collected at Kerguelen by the British Transit of Venus Expedition, E. A. SMITH writes:—Opportunity was taken some pages back of exhibiting the relations of the Molluscan fauna of Kerguelen Island to that of the Falklands and Patagonia; and it was pointed out that representatives of boreal types entered into its composition. Materials for similar comparisons between the Echinodermata indigenous to the same regions scarcely exist, but such as there are, make it apparent that what obtains in the Mollusca holds good also in the Echinodermata with respect to geographical distribution. . . . A similarity to certain boreal terms is exhibited by some of the species. Thus *Porania antarctica* strangely resembles *P. pulvillus* of the northern seas of Europe; the *Pedicellaster* represents another septentrional genus; *Pteraster affinis* imitates closely *Pt. militaris* of boreal waters. The genera *Ophioglypha* and *Ophiacantha* are almost cosmopolitan in distribution; yet the Kerguelen Island representative of the

Asterias rupicola,[1] Verrill.
„ *studeri*, Bell.
Luidiaster hirsutus, Studer.

OPHIUROIDEA :

Ophiogona lævigata, Studer.
Ophiolepis (*Ophioglypha*) *carinata*, Studer.
Ophiomyxa vivipara, Studer. Recorded from Cape, Falklands, and Magellan Strait.
Pectinura (*Ophioglypha*) *verrucosa*, Studer.

HOLOTHURIOIDEA :

Cuvieria [= *Psolus*] *porifera*,[2] Studer.
Sigmodota purpurea, Studer [= *Chirodota studerii*, Théel]. Recorded from Magellan Strait.
Trachythyone [= *Thyone*] *muricata*, Studer.

GEPHYREA :

Thalassema verrucosa, Studer.

ANNELIDA[3] :

Arenicola piscatorum, Cuvier, var.
Artacama proboscidea,[4] Malmgren. Recorded from North Atlantic.
Lumbricus kerguelarum, Grube.
Neottis spectabilis, Verrill.
Nereis antarctica, Verrill.
Ophryotrocha claparedii, Studer.
Polynoë (*Harmothoë*) *fullo*, Grube. Recorded from Magellan Strait.
Sabella costulata, Grube.

COPEPODA :

Harpacticus fulvus,[5] Fischer. Recorded from Europe.

former, *O. hexactis*, in colour and in *tout ensemble* approaches *O. Sarsii* of the Greenland coast.—(*Phil. Trans.*, vol. 168, pp. 270–1.)

[1] F. Leipolt doubtfully regards this as a synonym of *Asterias rugispina*, Stimpson, from Tierra del Fuego, Magellan Strait, and off Buenos Ayres (*Zeitschr. f. wiss. Zool.*, Bd. lix. p. 563, 1895).

[2] THÉEL considers the form named by STUDER *Cuvieria porifera* to be possibly identical with *Psolus ambulator*, Bell, from Australia.

[3] GRUBE and M'INTOSH referred specimens collected at Kerguelen to the Magellan Strait species *Hermadion longicirratus*, Kinberg, and *Hermadion magalhænse*, Kinberg, but an examination of Challenger specimens from Kerguelen convinced M'INTOSH that the Kerguelen species is distinct, and he named it *Hermadion kerguelensis*.

M'INTOSH considers the *Serpula patagonica* of GRUBE to be a synonym of *Serpula narconensis*, Baird.

STUDER records a species of *Nereis* without authority (*Nereis aprogenia*) from Kerguelen, 100 fathoms.

[4] GRUBE records the northern *Artacama proboscidea*, Malmgren, from Kerguelen ; his specimens possibly belong to *Artacama challengeriæ*, M'Intosh, which seems to be very frequent in Kerguelen waters.

[5] The occurrence of this species [*Harpacticus fulvus*] in Kerguelen Island is particularly interesting from the fact

AMPHIPODA[1]:

Anonyx kergueleni[2] (Miers).
Lysianassa kidderi, Smith.
Podocerus ornatus, Miers.

ISOPODA[3]:

Ægа semicarinata, Miers.
Cassidina emarginata, Guérin-Ménéville. Recorded from Patagonia, Magellan Strait, Falklands, and South Georgia.
,, *maculata*, Studer.
Dynamene eatoni, Miers.
Sphæroma gigas, Leach. Recorded from Patagonia, Australia, and New Zealand.

PYCNOGONIDA:

Nymphon gracilipes,[4] Miers.
Tanystylum styligerum, Miers.

LAMELLIBRANCHIATA[5]:

Anatina impressa, Watson *in litt.*

that it is found all over the European shores in precisely similar situations, that is to say in brackish pools, at or above high-water mark, which are liable to become warm through exposure to the sun's rays. These are in no respect distinguishable from European specimens—(G. S. BRADY, *Phil. Trans.*, vol. 168, p. 215.)

[1] PFEFFER records *Rhachotropis aculeatus* (Lepechin) from the Kerguelen region (*Ergebnisse der deutschen Polar-Expeditionen*); this is probably the species named by STEBBING *Rhachotropis kergueleni*.

[2] In the form of the antero-lateral angles of the cephalon, and of the postero-lateral angles of the third segment of the pleon, this species [*Anonyx kergueleni*] to some extent resembles (1) *Hippomedon holbölli*, Kröyer, as described by BOECK, as well as (2) *H. abyssi*, Goës, and (3) *Anonyx pumilus*, Lilljeborg—all from the Northern Sea. . . . The eyes, also, which are well marked in the species just referred to, are not visible in any of the specimens of *A. kergueleni*.—(E. J. MIERS, *Phil. Trans.*, vol. 168, p. 208.)

[3] STUDER'S *Serolis ovalis* is a synonym of *Serolis septemcarinata*, Miers, as STUDER himself supposed when he published his description.

[4] This species [*Nymphon antarcticum*=*N. gracilipes*] is allied to *N. grossipes*, O. Fab., as described by KRÖYER, from the northern seas, but differs somewhat in the length of the neck, and in the proportions of the joints of the legs and appendages.—(E. J. MIERS, *Phil. Trans.*, vol. 168, p. 212.)

[5] E. A. SMITH introduces his description of the Mollusca collected by the British Transit of Venus Expedition at Kerguelen thus:—The Malacological fauna resembles generally that of the Falkland Islands and South Patagonia. More than half of the genera and seven or eight of the species found at Kerguelen Island are known to occur at those localities, and further research will probably discover a still greater number of genera and species to be common to these two, longitudinally, so widely separated localities. With respect to their latitudes the difference is unimportant, since they both range between 49° and 54° S. lat. As the Cape of Good Hope, Tasmania, and South West Australia are the nearest points of mainland, it might be expected that some resemblance to the fauna of those countries might be observable. However, it is not so, as far as our present knowledge extends. Many of the shells from Kerguelen Island have the generally unattractive appearance, as regards coloration, which so frequently obtains in species found in cold climates. Indeed, some of them seem to be southern representatives of boreal types. The *Neobuccinum*, *Trophon*, *Saxicava*, *Kellia*, *Yoldia*, *Radula*, and *Doris*, are remarkable instances of similarity to northern forms.—(*Phil. Trans.*, vol. 168, p. 167.)

In the actual state of our knowledge, the malacological fauna of Kerguelen is composed of 26 species. This fauna is eminently austral. It is intimately related to that of New Zealand, by the presence of some common species (*Purpura striata, Venus stutchburyi, Mytilus canaliculus*), and by that of the genus *Struthiolaria*, which is also known

Arca (*Lissarca*) *rubro-fusca*, Smith. Recorded from Magellan Strait and South Georgia.

Kellia consanguinea,[1] Smith.

Kidderia [= *Modiolarca*] *minuta*, Dall. Recorded from Patagonia.

Lasea rubra (Montagu). Distribution world wide.

Lepton parasiticum, Dall (parasitic on *Hemiaster cavernosus*).

Modiolarca exilis, H. & A. Adams. Recorded from Falklands.

Mytilus canaliculus, Hanley. Recorded from Chili and New Zealand.

,, *edulis*,[2] Linné. A cosmopolitan species.

Saxicava bisulcata, Smith.

Venus (*Chione*) *stutchburyi*, Gray. Recorded from New Zealand and Sandwich Islands (?).

GASTEROPODA :

Admete (—— ?) *limnæaformis*, Smith.

Eatoniella kerguelenensis (Smith). Recorded from South Georgia.

Hydrobia pumilio, Smith.

Lamellaria kerguelensis, Studer.

Marsenia kerguelenensis, Studer.

Natica sculpta, Martens.

Patella aenea, Martyn.

,, *delesserti*, Philippi. Recorded from Magellan Strait.

,, (*Nacella*) *mytilina*, Gmelin. Recorded from Magellan Strait.

,, (or *Patinella*) *magellanica*, Gmelin. Recorded from Magellan Strait.

from Australia. On the other hand, it participates in character with those of the Strait of Magellan (*Siphonaria tristensis*, *Patella magellanica* and *delesserti*, *Kidderia minuta*), of the south of Chili (*Mytilus canaliculus*) and of the islands in the neighbourhood of the Cape of Good Hope (*Siphonaria tristensis*). Finally, it presents particular characters which imprint it, in spite of its relative poverty, with a certain seal of originality. In fact, of the 25 marine species composing it, we encounter 15 which have been found to be new to science. This is a proportion of about 60 per cent., a proportion veritably enormous, which may be perhaps explained by the isolation of the Kerguelen Islands and by their almost complete state of *terra incognita* in a malacological sense. The unique terrestrial species which lives at Kerguelen, *Helix hookeri*, is assuredly one of the *Helices* nearest to the Antarctic circle, the existence of which is known up to the present time.—(CROSSE, *Journ. de Conchyliologie*, sér. 3, tom. xvii. pp. 14–15, 1877.)

PFEFFER records *Modiolarca pusilla*, Gould, and *Mytilus ungulatus*, Reeve, from the Kerguelen region.—(*Ergebnisse der deutschen Polar-Expeditionen.*)

[1] At a first glance this species [*Kellia consanguinea*] might easily be mistaken for the European *Lasæa rubra*, to which it has a very great resemblance.—(E. A. SMITH, *Phil. Trans.*, vol., 168, p. 185.)

[2] Of *Mytilus edulis* SMITH writes :—No definite distinction can be traced in the shells (unfortunately only eleven in number) collected at Kerguelen, from specimens from the Dutch coast bought in the London market. The form of the shell (always more or less variable), colour of the exterior and interior, the hinge with the few irregular teeth, muscular scars, and the punctures in the interior towards the ventral margins, are precisely alike in both local forms. . . . I have closely examined the soft parts of four Kerguelen specimens, and . . . I find them to be exactly the same as in European specimens.—(*Phil. Trans.*, vol. 168, p. 189.)

This common species [*Mytilus edulis*] has become widely distributed, and differs considerably in form, colour, and size. HUTTON quotes it as occurring in New Zealand, and I have already identified it as coming from Kerguelen. —(SMITH, *Zool. Chall. Exp.*, part 35, p. 272.)

Purpura striata, Martyn. Recorded from New Zealand.
Rissoa kergueleni, Smith.
Scalaria symphylla, Martens.
Scissurella supraplicata, Smith.

Siphonaria redimiculum, Reeve
„ *tristensis*, Sowerby
} [=*Siphonaria* (*Liriola*) *tristensis*, Leach]. Recorded from Tristan da Cunha, Chili, Peru, Patagonia, and Falklands.

NUDIBRANCHIATA :

Doris tuberculata,[1] Cuvier [= ? *Archidoris kerguelenensis*, Bergh].

POLYZOA[2] :

Caberea boryi,[3] Audouin [= ? *Caberea darwinii*, Busk].
Cellularia cirrata, Ellis and Solander [= *Menipea cirrata*, Lamouroux]. Recorded from the Cape.
Crisia edwardsiana (d'Orbigny). Recorded from Patagonia, Tierra del Fuego, Australia, and New Zealand.
„ *kerguelensis*, Busk.
Diachoris costata, Busk. Recorded from Falklands and Australia.
Discoporella [= *Lichenopora*] *canaliculata*, Busk.
„ [„] *fimbriata*, Busk. Recorded from Tristan da Cunha, Tierra del Fuego, Chiloe, Chonos Archipelago, and Tasmania.

[1] A Nudibranch brought from Kerguelen Island by the Antarctic Expedition has been identified as a variety of this common European species [*Doris tuberculata*], by Mr P. S. ABRAHAM, who has recently been studying the species of this genus in the national collection. He says that it possesses no characters of specific distinction from *D. tuberculata*, and differs from it only in a few slight and unimportant particulars attributable to mere variation. . . . The undetermined *Doris* found by Dr KIDDER in tide pools at low-water in Royal Sound will very likely prove to be the same species.—(SMITH, *Phil. Trans.*, vol. 168, p. 183.)

STUDER doubtfully records *Doris tuberculata* from Kerguelen, but BERGH considers the form referred to as probably identical with his *Archidoris kerguelenensis* and distinct from the northern form.

[2] Of Mr EATON'S collection of Polyzoa from Kerguelen BUSK writes :—The collection affords nine or ten forms previously undescribed ; the remainder belong to a fauna which ranges from the southern extremity of S. America (which may be regarded as its "centre") to New Zealand in a westerly direction, one or two species extending even farther, to Australia and the Cape of Good Hope. It is observable that no Arctic form has been brought from Kerguelen Island, although some have been met with further south, two instances of the occurrence of the Arctic *Hornera lichenoides* obtained during the voyage of H.M.SS. "Erebus" and "Terror" having been communicated to me by Sir J. HOOKER. Mr EATON suspects their absence may be attributed to the shallowness of the areas searched by him, the greatest depth being not more than 10 fathoms.—(*Phil. Trans.*, vol. 168, p. 193.)

PFEFFER records *Lichenopora gignonensis*, Busk, and *Pedicellina australis*, Ridley, from the Kerguelen region (*Ergebnisse der deutschen Polar-Expeditionen*) ; in the same place he also gives *Pedicellina australis*, Jullien, from the Magellan Strait region.

[3] The form called by BUSK in the Transit of Venus Report *Caberea boryi*, Audouin, he subsequently considered to be distinct from the true *Caberea boryi*, and he names it *Caberea darwinii* in the Challenger Report, where he says :—"So far as I know at present, the true *Caberea boryi* of AUDOUIN is confined to the Mediterranean and Atlantic regions, as far north as our own coast, and as far south, in all probability, as the Cape (Algoa Bay)."—(*Zool. Chall. Exp.* part 30, p. 29.)

Discoporella [*Lichenopora*] *infundibuliformis*, Busk.
Lepralia eatoni, Busk.
„ *galeata*, Busk. Recorded from Falklands and Tierra del Fuego.
„ *margaritifera* (Quoy and Gaimard). Recorded from Falklands and Tierra del Fuego.
? *Membranipora spinosa*[1] (Quoy and Gaimard).
Menipea fuegensis, Busk [= *M. aculeata* (d'Orbigny)]. Recorded from Magellan Strait, Patagonia, and Falklands.
„ *patagonica*, Busk. Recorded from Patagonia and Falklands.
Pustulopora delicatula, Busk. Recorded from Australia and Madeira (?).
Tubulipora organizans, d'Orbigny. Recorded from Falklands.
„ *stellata*, Busk.

BRACHIOPODA :
Waldheimia dilatata (Lamarck) [= *W. venosa* (Solander)]. Recorded from Patagonia and Falklands.

FISHES :
Notothenia antarctica, Peters.
„ *coriiceps*, Rich. Recorded from South Georgia and Auckland Islands.
„ *purpuriceps*, Rich.
„ *tesselata*, Rich (?). Recorded from Falkland Islands.

The following species might perhaps be included among the Kerguelen fauna, but their habitats are only vaguely specified :—

CORALS :
Errina fissurata, Gray. Antarctic Ocean.

SIPHONOPHORA :
Armenista antarctica (Eschscholtz). Antarctic Ocean ; also Indian Ocean and Cape of Good Hope.

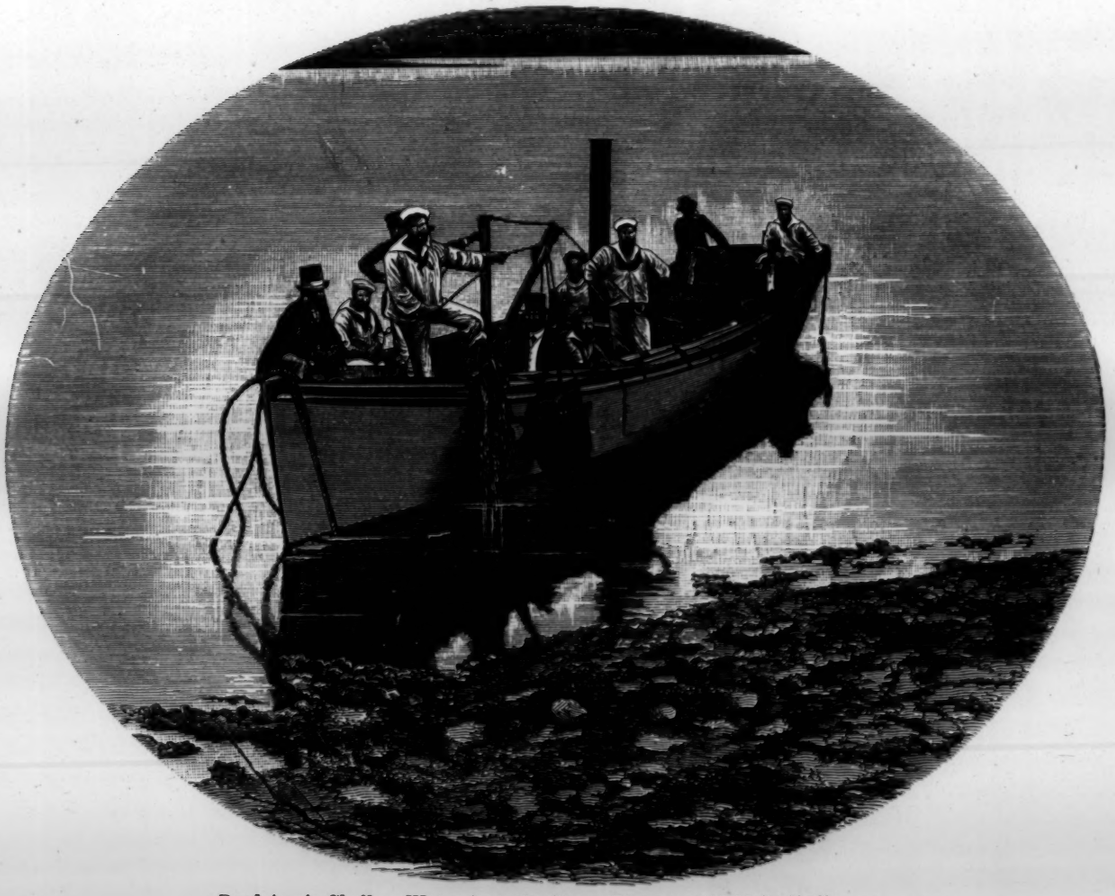
HOLOTHURIOIDEA :
Ocnus [= *Cucumaria*] *vicarius*, Bell. Antarctic Sea.

CIRRIPEDIA :
Coronula balænaris (Gmelin). Attached to whales in the Southern Ocean.

FISHES :
Notothenia phocæ, Rich. "Eismeer" (according to Pfeffer).

[1] BUSK records *Membranipora spinosa* (Quoy and Gaimard) from Kerguelen in the Transit of Venus Report, and in the Challenger Report he gives *Membranipora spinosa*, d'Orbigny, from Australia and South Patagonia, but he makes no mention of Kerguelen.

The foregoing enumeration (List V.) of species recorded from Kerguelen, from sources other than the Challenger Expedition, includes about 112 species belonging to about 87 genera. Some of these species require verification, but looking upon them for the present as authentic, and adding them to the Challenger List (List IV.), we should have a total of 645 species of Metazoa, belonging to 371 genera, recorded from the shallow waters of the Kerguelen Region in depths not exceeding 150 fathoms. The proportion of genera to species would thus be as 1 to 1·74, while the proportion of genera to species in List IV. is as 1 to 1·64, due to the fact that, while all the species in List V. are distinct from those in List IV., about half the genera in List V. are already included in List IV.



Dredging in Shallow Water from the Steam Pinnace of H.M.S. Challenger.

LIST VI.

IDENTICAL AND CLOSELY-ALLIED SPECIES FOUND IN THE EXTRA-TROPICAL REGIONS OF THE NORTHERN AND SOUTHERN HEMISPHERES, AND UNKNOWN HITHERTO WITHIN THE TROPICS.

Frequent reference has been made in the foregoing pages to the identity and close resemblance of species recorded from the extra-tropical regions of the Northern and Southern Hemispheres, which, however, up to the present time, are unknown from the intervening tropical zone. For the information of those interested in the subject, the names of the identical and closely-allied species[1] which show this peculiar distribution are brought together in the following lists.

In the first place we give a list of 90 identical species from the Northern and Southern Hemispheres unrecorded from within the tropics:—

MONAXONIDA :

Axinella erecta.
Halichondria sanguinea.
Isodictya rosea.
Myxilla plumosa.
Suberites carnosus.

HEXACTINELLIDA :

Aulocalyx irregularis.
Chonelasma lamella.

CALCAREA :

Sycon capillosum.

ACTINIARIA :

Cereus spinosus.
Liponema multiporum.

CORALS :

Flabellum apertum.

[1] For further species known only from north and south of the tropics, and unrecorded from the intervening tropics, which do not come within the scope of this paper, see Challenger Report, Summary of Results, pp. 1446-1449.

HYDROIDA :

Campanularia cylindrica.
Eudendrium rameum.
Obelia geniculata.

CRINOIDEA :

Antedon abyssicola.

ASTEROIDEA :

Dytaster exilis.
Pontaster forcipatus.

OPHIUROIDEA :

Ophiacantha rosea.
Ophiernus vallincola.
Ophiocten hastatum.
„ *sericeum.*
Ophioglypha bullata.
„ *irrorata.*

ECHINOIDEA :

Phormosoma hoplacantha.
Pourtalesia phiale.

HOLOTHURIOIDEA :

Elpidia glacialis.
Euphronides depressa.
Holothuria thomsoni.
Kolga nana.
Lætmogone wyville-thomsoni.

NEMERTEA :

Drepanophorus serraticollis.
Pelagonemertes rollestoni.

ANNELIDA :

Artacama proboscidea.
Eunice ærstedi.
Eupista darwini.
Placostegus ornatus.
Terebellides strœmi.

OSTRACODA :

Cythere irpex.
„ *suhmi.*
Krithe tumida.
Paradoxostoma abbreviatum.
Pseudocythere caudata.
Sclerochilus contortus.
Xestoleberis depressa.
„ *expansa.*

COPEPODA :

Harpacticus fulvus.

CIRRIPEDIA :

Scalpellum velutinum.

AMPHIPODA :

Eusirus longipes.
Podocerus falcatus.
„ *tuberculatus.*

ISOPODA :

Eurycope fragilis.
Neotanais americanus.
Typhlotanais kerguelenensis.

SCHIZOPODA :

Boreomysis scyphops.
Gnathophausia gigas.

MACRURA :

Glyphocrangon rimapes.

ANOMURA :

Munidopsis antonii.
„ *subsquamosa.*

LAMELLIBRANCHIATA :

Glomus nitens.
Kellia suborbicularis.
Mytilus edulis.

SCAPHOPODA AND GASTEROPODA :

Dentalium keras.
Homalogyra atomus.
Ianthina rotundata.
Natica (Lunatia) grönlandica.
Odostomia rissoïdes.
Puncturella noachina.
Trochus (Margarita) infundibulum.

NUDIBRANCHIATA :

? *Doris tuberculata.*

POLYZOA :

Cribrilina monoceros.
Crisia eburnea.
Diachoris magellanica.
Escharoides verruculata.
Hornera lichenoides.
„ *violacea.*
Idmonea atlantica.
„ *marionensis.*
„ *milneana.*
Kinetoskias cyathus.
Membranipora crassimarginata
„ *galeata.*
Pustulopora deflexa.
„ *delicatula.*
„ *proboscidea.*
„ *proboscidioides.*

BRACHIOPODA :

Platydia anomioides.

TUNICATA :

Pyrosoma spinosum.

FISHES :

Halosaurus macrochir.
Stomias boa.
Synaphobranchus bathybius.

LIST VI *a*.

In addition to the identical species noted in the preceding list as having been recorded from both the Northern and Southern Hemispheres and unknown in the intervening tropical zone, we give now, in the second place, a list of representative or apparently closely-allied species occurring in northern and southern waters respectively, and so far as is known not recorded from the tropics.

Southern Species.	Northern Representatives.
Monaxonida :	
Amphilectus apollinis.	*Artemisina suberitoides.*
Desmacidon (H.) kerguelenensis.	*Desmacidon (H.) palmata.*
Gellius flagellifer.	*Gellius vagabundus* of Vosmaer.
Iophon chelifer.	*Iophon piceum.*
Myxilla nobilis.	*Myxilla paupertas.*
Pachychalina pedunculata.	*Pachychalina caulifera.*
Phakellia papyracea.	*Cribrochalina ambigua.* / *Isodictya infundibuliformis.*
Hexactinellida :	
Caulophacus latus.	*Caulophacus elegans.*
Crinoidea :	
Antedon exigua.	*Antedon tenella.*
Asteroidea :	
Leptoptychaster antarcticus.	*Leptoptychaster arcticus.*
Porania antarctica.	*Porania pulvillus.*
Pteraster affinis.	*Pteraster militaris.*
Solaster subarcuatus.	*Solaster endeca.*
Ophiuroidea :	
Ophiacantha imago.	*Ophiacantha anomala.*
Ophioglypha hexactis.	*Ophioglypha sarsii.*
,, *meridionalis.*	,, *robusta.*
Annelida :	
Lumbriconereis kerguelensis.	*Lumbriconereis nardonis.*
Nereis (P.) eatoni.	*Nereis dumerilii.*

Southern Species.	Northern Representatives.
Ostracoda :	
Cythere foveolata.	*Cythere borealis.*
„ *kerguelenensis.*	„ *albomaculata.*
Cytheropteron assimile.	*Cytheropteron latissimum.*
„ *scaphoides.*	„ *subcircinatum.*
Cytherura lilljeborgi.	*Cytherura clathrata.*
Cirripedia :	
Balanus corolliformis.	*Balanus hirsutus.*
Amphipoda :	
Amphilochus marionis.	*Amphilochus tenuimanus.*
Andania abyssorum.	*Andania abyssi.*
Euthemisto thomsoni.	*Euthemisto bispinosa.*
Liljeborgia consanguinea.	*Liljeborgia pallida.*
Metopa nasutigenes.	*Metopa nasuta.*
Orchomene abyssorum. }	*Orchomene musculosus.*
„ *cavimanus.* }	
Pardalisca marionis.	*Pardalisca cuspidata.*
Isopoda :	
Leptognathia australis.	*Leptognathia longiremis.*
Pleurogonium albidum. }	*Pleurogonium rubicundum*
„ *serratum.* }	
Cumacea :	
Campylaspis nodulosa.	*Campylaspis verrucosa.*
Diastylis horrida.	*Diastylis lucifera.*
Leucon assimilis.	*Leucon nasicus.*
Anomura :	
Lithodes murrayi.	*Lithodes maia.*
Pycnogonida :	
Colossendeis megalonyx.	*Colossendeis proboscidea.*
Nymphon brachyrhynchus.	*Nymphon strœmii.*
„ *brevicaudatum.*	„ *brevitarse.*
„ *gracilipes.*	„ *grossipes.*

Southern Species.	Northern Representatives.
Lamellibranchiata :	
Cardita astartoides.	*Cardita borealis.*
Cryptodon marionensis.	*Cryptodon flexuosus.*
	„ *gouldii.*
Neæra fragilissima.	*Neæra curta.*
Thracia meridionalis.	*Thracia truncata.*
Gasteropoda :	
Natica fartilis.	*Natica affinis.*
„ (*A.*) *suturalis.*	„ *islandica.*
Trophon declinans.	*Trophon truncatus.*
Turritella austrina.	*Turritella terebra.*
Cephalopoda :	
Bathyteuthis abyssicola.	*Bentheoteuthis megalops.*
Tunicata :	
Ascidia challengeri.	*Ascidia mentula.*
Fishes :	
Bathysaurus ferox.	*Bathysaurus agassizii*
Haplochitonidæ.	Salmonoids.
Chænichthys. }	Cottoids.
Notothenia. }	

Cythere dictyon, Brady. A cosmopolitan species, taken in the Kerguelen Region both in deep and in shallow water.

LIST VII.

Foraminifera observed in the Deposits from the Kerguelen Region at various Depths.

The following species of Foraminifera were observed in the deposits obtained in the Southern Indian Ocean during the cruise of the Challenger between the Cape of Good Hope and Australia to the south of lat. 40° S., viz. :—Station 144, 1570 fathoms; Station 146, 1375 fathoms; Station 149 (Kerguelen), 20 to 120 fathoms; Station 150, 150 fathoms; Station 151 (Heard Island), 75 fathoms; Station 153, 1675 fathoms; Station 157, 1950 fathoms; Station 158, 1800 fathoms; and Station 160, 2600 fathoms. The pelagic species are indicated by an asterisk *.

Nubecularia inflata, Brady.
Biloculina bulloides, d'Orbigny.
„ *depressa*, d'Orbigny.
„ „ var. *murrhyna*, Schwager.
„ „ var. *serrata*, Brady.
„ *elongata*, d'Orbigny.
„ *irregularis*, d'Orbigny.
„ *ringens* (Lamarck).
„ *sphæra*, d'Orbigny.
„ *tubulosa*, Costa.
Spiroloculina planulata (Lamarck).
„ *tenuis* (Czjzek).
Miliolina auberiana (d'Orbigny).
„ *bucculenta*, Brady.
„ *circularis* (Bornemann).
„ *fichteliana* (d'Orbigny).
„ *oblonga* (Montagu).
„ *seminulum* (Linné).
„ *subrotunda* (Montagu).
„ *venusta* (Karrer).
Articulina funalis, Brady.
„ „ var. *inornata*, Brady.
Ophthalmidium inconstans, Brady.
Planispirina celata (Costa).
Cornuspira foliacea (Philippi).
„ *involvens*, Reuss.
Orbitolites tenuissima, Carpenter.
Keramosphæra murrayi, Brady.
Astrorhiza angulosa, Brady.
„ *arenaria*, Norman.
„ *crassatina*, Brady.
„ *granulosa*, Brady.
„ sp. (?).
Pelosina cylindrica, Brady.
Pelosina rotundata, Brady.
Storthosphæra sp. (?).
Technitella legumen, Norman.
Bathysiphon filiformis, Sars.
Psammosphæra fusca, Schulze.
Saccammina sphærica, Sars.
Jaculella obtusa, Brady.
Hyperammina elongata, Brady.
„ *ramosa*, Brady.
„ *vagans*, Brady.
Marsipella cylindrica, Brady.
Rhabdammina abyssorum, Sars.
„ *discreta*, Brady.
Aschemonella catenata (Norman).
„ *ramuliformis*, Brady.
Rhizammina algæformis, Brady.
Reophax adunca, Brady.
„ *ampullacea*, Brady.
„ *cylindrica*, Brady.
„ *dentaliniformis*, Brady.
„ *difflugiformis*, Brady.
„ *distans*, Brady.
„ *fusiformis* (Williamson).
„ *guttifera*, Brady.
„ *nodulosa*, Brady.
„ *pilulifera*, Brady.
„ *scorpiurus*, Montfort.
„ *spiculifera*, Brady.
Haplophragmium agglutinans (d'Orbigny).
„ *canariense* (d'Orbigny).
„ *foliaceum*, Brady.
„ *globigeriniforme* (Parker and Jones).
„ *glomeratum*, Brady.

Haplophragmium latidorsatum (Bornemann).
„ *nanum*, Brady.
„ *rotulatum*, Brady.
„ *scitulum*, Brady.
„ *turbinatum*, Brady.
Placopsilina bulla, Brady.
„ *cenomana* (d'Orbigny).
„ *vesicularis*, Brady.
Thurammina albicans, Brady.
„ *compressa*, Brady.
„ *papillata*, Brady.
Hormosina carpenteri, Brady.
„ *ovicula*, Brady.
Ammodiscus charoides (Jones and Parker).
„ *gordialis* (Jones and Parker).
„ *schoneanus*, Siddall.
„ *tenuis*, Brady.
Trochammina galeata, Brady.
„ *lituiformis*, Brady.
„ *pauciloculata*, Brady.
„ *trullissata*, Brady.
Webbina clavata, Jones and Parker.
„ *hemisphærica*, Jones, Parker, and Brady.
Cyclammina cancellata, Brady.
„ *orbicularis*, Brady.
„ *pusilla*, Brady.
Textularia concava (Karrer).
Verneuilina pygmœa (Egger).
Gaudryina pupoides, d'Orbigny.
Clavulina communis, d'Orbigny.
Bulimina aculeata, d'Orbigny.
„ *marginata*, d'Orbigny.
„ *rostrata*, Brady.
„ *subteres*, Brady.
Virgulina schreibersiana, Czjzek.
„ *squamosa*, d'Orbigny
„ *subdepressa*, Brady.
Bolivina punctata, d'Orbigny.
„ *reticulata*, Hantken.
Pleurostomella brevis, Schwager.
„ (?) sp.
Cassidulina bradyi, Norman.
„ *crassa*, d'Orbigny.
„ *lævigata*, d'Orbigny.
„ *subglobosa*, Brady.
Ehrenbergina serrata, Reuss.
Lagena acuta (Reuss).
„ *acuticosta*, Reuss.
„ *alveolata*, Brady.
„ „ var. *substriata*, Brady.
„ *apiculata*, Reuss.
„ *auriculata*, Brady.
„ *botelliformis*, Brady.
Lagena clavata (d'Orbigny).
„ *distoma*, Parker and Jones.
„ *exsculpta*, Brady.
„ *feildeniana*, Brady.
„ *fimbriata*, Brady.
„ *formosa*, Schwager.
„ „ var. *favosa*, Brady.
„ *globosa* (Montagu).
„ *gracilis*, Williamson.
„ *gracillima* (Seguenza).
„ *hertwigiana*, Brady.
„ *hexagona* (Williamson).
„ *interrupta*, Williamson.
„ *lævigata* (Reuss).
„ *lævis* (Montagu).
„ *lineata* (Williamson).
„ *longispina*, Brady.
„ *marginata* (Walker and Boys).
„ „ var. *semimarginata*, Reuss.
„ *orbignyana* (Seguenza).
„ *quadralata*, Brady.
„ *quadricostulata*, Reuss.
„ *semistriata*, Williamson.
„ *squamosa* (Montagu).
„ *staphyllearia* (Schwager).
„ *stelligera*, Brady.
„ *striata* (d'Orbigny).
„ *sulcata* (Walker and Jacob).
„ *truncata*, Brady.
Nodosaria calomorpha, Reuss.
„ *communis*, d'Orbigny.
„ *mucronata*, Neugeboren.
„ *obliqua* (Linné).
„ *roemeri* (Neugeboren).
„ (*Glandulina*) *lævigata*, d'Orbigny.
„ („) *rotundata*, Reuss.
„ sp. (?).
Marginulina costata (Batsch).
Vaginulina legumen (Linné).
„ *linearis* (Montagu).
Cristellaria convergens, Bornemann.
„ *crepidula* (Fichtel and Moll).
„ *cultrata* (Montfort).
„ sp. (?).
Polymorphina angusta, Egger.
„ *lanceolata*, Reuss.
„ *sororia*, Reuss.
„ „ var. *cuspidata*, Brady.
„ *thouini*, d'Orbigny.
Uvigerina aculeata, d'Orbigny.
„ *angulosa*, Williamson.
„ *asperula*, Czjzek.
„ *brunnensis*, Karrer.

Uvigerina pygmæa, d'Orbigny.
„ *tenuistriata*, Reuss.
„ sp. (?).
Sagrina raphanus, Parker and Jones.
**Globigerina bulloides*, d'Orbigny.
* „ „ var. *triloba*, Reuss.
* „ *dubia*, Egger.
* „ *dutertrei*, d'Orbigny.
* „ *inflata*, d'Orbigny.
**Orbulina universa*, d'Orbigny.
**Pullenia obliquiloculata*, Parker and Jones.
„ *quinqueloba*, Reuss.
„ *sphæroides* (d'Orbigny).
Sphæroidina bulloides, d'Orbigny.
Spirillina decorata, Brady.
„ *limbata*, Brady.
„ *obconica*, Brady.
„ *tuberculata*, Brady.
„ *vivipara*, Ehrenberg.
Patellina corrugata, Williamson.
Discorbina araucana (d'Orbigny).
„ *parisiensis* (d'Orbigny).
„ *rosacea* (d'Orbigny).
„ *vilardeboana* (d'Orbigny).
Truncatulina akneriana (d'Orbigny).
„ *haidingerii* (d'Orbigny).
„ *lobatula*, Walker and Jacob.
„ *pygmæa*, Hantken.
„ *tenera*, Brady.
„ *ungeriana* (d'Orbigny).
„ *wuellerstorfi* (Schwager).
Anomalina grosserugosa (Gümbel).
**Pulvinulina crassa* (d'Orbigny).
„ *elegans* (d'Orbigny).
„ *exigua*, Brady.
* „ *micheliniana* (d'Orbigny).
* „ *patagonica* (d'Orbigny).
„ *pauperata*, Parker and Jones.
„ *umbonata*, Reuss.
Rotalia orbicularis, d'Orbigny.
„ *soldanii*, d'Orbigny.
Nonionina depressula (Walker and Jacob).
„ *pompilioides* (Fichtel and Moll).
„ *umbilicatula* (Montagu).
Polystomella crispa (Linné).
„ *macella* (Fichtel and Moll).
„ *striatopunctata* (Fichtel and Moll).

In the foregoing list, 220 species and varieties of Foraminifera are enumerated, belonging to 63 genera; the number of pelagic species amounts to 10, or less than 5 per cent. of the total number. It may be pointed out that the total number of species observed in the deposits from all these different depths in the Kerguelen Region does not equal the number of species in the deposit collected off Raine Island, Torres Strait. Generally speaking, in the shallow waters of the tropics the genera and species of Foraminifera, especially those which secrete carbonate of lime, are more abundant than in the colder regions north and south.

118	species	(or 54 per cent.)	were taken	each	at a single	Station,
38	„	(„ 17 „)	„	„	two	Stations,
26	„	(„ 12 „)	„	„	three	„
19	„	(„ 9 „)	„	„	four	„
10	„	(„ 4 „)	„	„	five	„
3	„	(„ 1 „)	„	„	six	„
4	„	(„ 2 „)	„	„	seven	„
2	„	(„ 1 „)	„	„	eight	„
220	„	100	„			

LIST VII *a*.

The following is a list of those species taken at more than one Station, the number of Stations being indicated in brackets after the name :—

Biloculina depressa (7).
„ „ var. *murrhyna* (3).
„ *elongata* (2).
„ *irregularis* (2).
„ *ringens* (3).
„ *sphæra* (5).
Spiroloculina tenuis (2).
Miliolina auberiana (2).
Miliolina circularis (2).
„ *oblonga* (3).
„ *seminulum* (5).
„ *venusta* (3).
Articulina funalis (2).
Ophthalmidium inconstans (2).
Astrorhiza angulosa (2).
Pelosina cylindrica (2).
Psammosphæra fusca (4).
Saccammina sphærica (3).
Hyperammina ramosa (3).
„ *vagans* (3).
Marsipella cylindrica (2).
Rhabdammina abyssorum (3).
Rhizammina algæformis (5).
Reophax adunca (3).
„ *dentaliniformis* (3).
„ *difflugiformis* (4).
„ *distans* (3).
„ *guttifera* (2).
„ *nodulosa* (2).
„ *pilulifera* (3).
„ *scorpiurus* (7).
Haplophragmium agglutinans (2).
„ *canariensis* (2).
„ *globigeriniforme* (4)
„ *latidorsatum* (4).
„ *turbinatum* (4).
Thurammina papillata (3).
Hormosina ovicula (2).
Ammodiscus charoides (4).
Trochammina pauciloculata (2).
„ *trullissata* (4).
Webbina clavata (5).
Verneuilina pygmæa (4).
Gaudryina pupoides (4).
Clavulina communis (5).
Bulimina aculeata (2).
Virgulina schreibersiana (2).
Bolivina punctata (2).
Cassidulina crassa (6).
„ *lævigata* (2).
„ *subglobosa* (6).
Lagena acuta (3).
„ *acuticosta* (2).
„ *alveolata* (2).
„ *globosa* (3).
„ *gracilis* (2).
„ *gracillima* (3).
„ *interrupta* (2).
„ *lævigata* (8).
„ *lævis* (7).
„ *lineata* (2).
„ *longispina* (2).
„ *marginata* (4).
„ *orbignyana* (2).
„ *squamosa* (3).
„ *staphyllearia* (3).
„ *stelligera* (3).
„ *striata* (4).
„ *sulcata* (5).
Nodosaria communis (3).
Vaginulina legumen (2).
Polymorphina angusta (2).
„ *lanceolata* (2).
„ *sororia* (2).
Uvigerina angulosa (3).
„ *asperula* (5).
„ *pygmæa* (4).
Globigerina bulloides (8).
„ *dutertrei* (3).
„ *inflata* (5).
Orbulina universa (4).
Pullenia quinqueloba (7).
„ *sphæroides* (4).
Sphæroidina bulloides (5).
Patellina corrugata (2).
Discorbina araucana (2).
„ *parisiensis* (2).
Truncatulina haidingerii (2).
„ *lobatula* (6).
„ *pygmæa* (4).
„ *tenera* (2).
„ *ungeriana* (3).
„ *wuellerstorfi* (3).
Anomalina grosserugosa (2).
Pulvinulina crassa (4).
„ *exigua* (3).
„ *micheliniana* (5).
„ *patagonica* (4).
Rotalia soldanii (4).
Nonionina pompilioides (4).
„ *umbilicatula* (3).
Polystomella striatopunctata (2).

In List VII. are included 6 unnamed species, which must be excluded in any discussion of distribution; there are, besides, 8 varieties enumerated as well as the species to which they belong, leaving altogether 206 distinct species, the distribution of which may be examined in detail.

4 species (or 2 per cent. of the total number) are known to occur only to the *south* of the southern tropic;
7 species (or 3 per cent. of the total number) extend *within* (but not north of) the tropics;
16 species (or 7 per cent. of the total number) are found to the *north* of (but not within) the tropics; and
179 species (or 82 per cent. of the total number) are known *both* from tropical and extra-tropical regions.

LIST VII *b*.

The following is a list of the 4 species recorded only from the south of the tropics, 2 of which are known only from the area under consideration, the remaining 2 extending into the South Atlantic and South Pacific, as indicated :—

Keramosphæra murrayi—Known only from this area.
Reophax ampullacea—Known only from this area.
Cyclammina orbicularis—Known outside this area from South Pacific and South Atlantic, 1100 and 1900 fathoms.
Lagena quadralata—Known outside this area from South Atlantic, 2200 fathoms.

LIST VII *c*.

The following is a list of the 7 species known from within (but not recorded to the north of) the tropics, the distribution of each species outside the area under consideration being briefly indicated :—

Nubecularia inflata—Islands of tropical Pacific (Tonga, Tahiti, Admiralty, Sandwich), 17 to 420 fathoms.
Miliolina circularis—Bass Strait and Admiralty Islands, 15 to 150 fathoms.
Bolivina reticulata—Tropical and South Atlantic and tropical Pacific, 130 to 1425 fathoms.
Pleurostomella brevis—Tropical Pacific (Ki Islands), 129 fathoms.
Lagena botelliformis—Tropical and South Atlantic and South Pacific, shallow water to 2350 fathoms.
Uvigerina aculeata—South Atlantic, South and tropical Pacific, 240 to 1975 fathoms.
Spirillina obconica—Tropical Pacific (Admiralty Islands), 17 fathoms.

LIST VII *d*.

The following is a list of the 16 species known from the north of the northern tropic but not recorded from between the tropics, the distribution of each species outside the area under consideration being briefly indicated :—

Orbitolites tenuissima—North Atlantic and Mediterranean, 64 to 1700 fathoms.
Astrorhiza angulosa—South Pacific and North Atlantic, 410 to 1000 fathoms.
„ *arenaria*—North and South Atlantic and South Pacific, 150 to 650 fathoms.
„ *crassatina*—Faroe Channel, 640 fathoms.
„ *granulosa*—North Atlantic, 1000 and 1700 fathoms.
Reophax cylindrica—North Atlantic and North Pacific, 1750 and 1875 fathoms.
Placopsilina bulla—North and South Atlantic and South Pacific, 410 to 2160 fathoms.
vesicularis—North and South Atlantic and South Pacific, 410 to 1900 fathoms.

Thurammina albicans—North and South Pacific and South Atlantic, 1825 to 2050 fathoms.
„ *compressa*—North Atlantic, 630 fathoms.
Ammodiscus schoneanus—North Atlantic and North Pacific, shallow water to 3950 fathoms.
Webbina hemisphærica—North and South Atlantic and South Pacific, 25 to 1900 fathoms.
Lagena lineata—North and South Atlantic, North and South Pacific, shore to 1875 fathoms.
Polymorphina thouini—Bass Strait and Mediterranean, 38 and 90 fathoms.
Uvigerina brunnensis—North and South Pacific, South Atlantic, Magellan Strait, 245 to 2050 fathoms.
Discorbina parisiensis—North Atlantic, shallow water.

LIST VII *e*.

The following is a list of the 179 species known both from tropical and extra-tropical regions, the distribution of each species outside the area under consideration being briefly indicated:—

Biloculina bulloides—North and South Atlantic, South and tropical Pacific, shallow water to 2750 fathoms.
„ *depressa*—Cosmopolitan, shore to 3000 fathoms.
„ *elongata*—Cosmopolitan, shore to 2025 fathoms.
„ *irregularis*—North, tropical and South Atlantic, tropical Pacific, 350 to 1415 fathoms.
„ *ringens*—Cosmopolitan, shore to 3000 fathoms.
„ *sphæra*—Cosmopolitan, shallow water to 2300 fathoms.
„ *tubulosa*—North and tropical Atlantic, South and tropical Pacific, 210 to 1240 fathoms.
Spiroloculina planulata—Cosmopolitan (except Arctic), shore to 2600 fathoms.
„ *tenuis*—Cosmopolitan, shallow water to 2750 fathoms.
Miliolina auberiana—Mediterranean, North and tropical Atlantic, Magellan Strait, tropical Pacific, shallow water to 2435 fathoms.
„ *bucculenta*—Arctic, North and tropical Atlantic, 390 to 1785 fathoms.
„ *fichteliana*—North and tropical Atlantic, Indian Ocean, North Pacific, shore and shallow water.
„ *oblonga*—Cosmopolitan, shore to 3000 fathoms.
„ *seminulum*—Cosmopolitan, shore to 3000 fathoms.
„ *subrotunda*—Arctic, North, tropical and South Atlantic, tropical Pacific, shore to 150 fathoms.
„ *venusta*—North, tropical and South Atlantic, North, tropical and South Pacific, 150 to 2740 fathoms.
Articulina funalis—North Atlantic and tropical Pacific, 37 to 950 fathoms.
Ophthalmidium inconstans—North, tropical and South Atlantic, North, tropical and South Pacific, 100 to 2300 fathoms.
Planispirina celata—Cosmopolitan, 28 to 1630 fathoms.
Cornuspira foliacea—Cosmopolitan, shallow water to 1500 fathoms.
„ *involvens*—Cosmopolitan, 7 to 1900 fathoms.
Pelosina cylindrica—North, tropical and South Atlantic, North, tropical and South Pacific, 620 to 2900 fathoms.
„ *rotundata*—North and tropical Atlantic, North, tropical and South Pacific, 350 to 2050 fathoms.
Technitella legumen—North, tropical and South Atlantic, North, tropical and South Pacific, 60 to 2350 fathoms.
Bathysiphon filiformis—North, tropical and South Atlantic, North, tropical and South Pacific, 410 to 1900 fathoms.
Psammosphæra fusca—North, tropical and South Atlantic, North, tropical and South Pacific, 45 to 2800 fathoms.
Saccammina sphærica—Arctic, North and tropical Atlantic, North and South Pacific, 89 to 2050 fathoms.
Jaculella obtusa—North and tropical Atlantic, North Pacific, 350 to 1875 fathoms.
Hyperammina elongata—Cosmopolitan, 80 to 3124 fathoms.
„ *ramosa*—Cosmopolitan, 60 to 3000 fathoms.
„ *vagans*—Cosmopolitan, 15 to 2900 fathoms.
Marsipella cylindrica—North and South Atlantic, North, tropical and South Pacific, 210 to 1900 fathoms.
Rhabdammina abyssorum—Cosmopolitan, 108 to 2435 fathoms.
„ *discreta*—Cosmopolitan, 20 to 2475 fathoms.
Aschemonella catenata—North, tropical and South Atlantic, North, tropical and South Pacific, 390 to 2900 fathoms.
„ *ramuliformis*—North, tropical and South Atlantic, tropical and North Pacific, 1125 to 3125 fathoms.
Rhizammina algæformis—North, tropical and South Atlantic, North, tropical and South Pacific, 150 to 2900 fathoms.
Reophax adunca—North, tropical and South Atlantic, North, tropical and South Pacific, 540 to 2950 fathoms.
„ *dentaliniformis*—Cosmopolitan, 20 to over 3000 fathoms.
„ *difflugiformis*—Cosmopolitan, 55 to 3950 fathoms.

Reophax distans—North, tropical and South Atlantic, North, tropical and South Pacific, 355 to 2775 fathoms.
„ *fusiformis*—Arctic, North and South Atlantic, tropical Pacific, 40 to 1900 fathoms.
„ *guttifera*—North and South Atlantic, North, tropical and South Pacific, 540 to 2350 fathoms.
„ *nodulosa*—Cosmopolitan, shallow water to 3150 fathoms.
„ *pilulifera*—North, tropical and South Atlantic, North, tropical and South Pacific, 800 to 2900 fathoms.
„ *scorpiurus*—Cosmopolitan, 3 to 3950 fathoms.
„ *spiculifera*—Tropical Atlantic, North, tropical and South Pacific, 255 to 2350 fathoms.
Haplophragmium agglutinans—Cosmopolitan, 2 to 3125 fathoms.
„ *canariense*—Cosmopolitan, shallow water to 3950 fathoms.
„ *foliaceum*—North and South Atlantic, North, tropical and South Pacific, 345 to 2600 fathoms.
„ *globigeriniforme*—Cosmopolitan, 15 to 3950 fathoms.
„ *glomeratum*—North, tropical and South Atlantic, North, tropical and South Pacific, 14 to 2740 fathoms.
„ *latidorsatum*—Cosmopolitan, 113 to 3950 fathoms.
Haplophragmium nanum—Arctic, North, tropical and South Atlantic, Magellan Strait, North and South Pacific, 55 to 3125 fathoms.
„ *rotulatum*—North, tropical and South Atlantic, North and South Pacific, 1000 to 3150 fathoms.
„ *scitulum*—North, tropical and South Atlantic, Magellan Strait, North and South Pacific, 400 to 2900 fathoms.
„ *turbinatum*—North, tropical and South Atlantic, North and tropical Pacific, 150 to 2450 fathoms.
Placopsilina cenomana—North, tropical and South Atlantic, Mediterranean, Gulf of Suez, tropical Pacific, 3 to 1900 fathoms.
Thurammina papillata—Cosmopolitan, 45 to 2740 fathoms.
Hormosina carpenteri—North and tropical Atlantic, tropical and South Pacific, 54 to 1940 fathoms.
„ *ovicula*—North and South Atlantic, tropical and North Pacific, 1070 to 3950 fathoms.
Ammodiscus charoides—North, tropical and South Atlantic, Mediterranean, Red Sea, North, tropical and South Pacific, shallow water to 2575 fathoms.
„ *gordialis*—Cosmopolitan, 55 to 3125 fathoms.
„ *tenuis*—North and tropical Atlantic, Magellan Strait, North, tropical and South Pacific, 210 to 2350 fathoms.
Trochammina galeata—North, tropical and South Atlantic, North, tropical and South Pacific, 390 to 2750 fathoms.
„ *lituiformis*—North and tropical Atlantic, tropical and South Pacific, 390 to 2350 fathoms.
„ *pauciloculata*—North, tropical and South Atlantic, North, tropical and South Pacific, 173 to 3950 fathoms.
„ *trullissata*—North, tropical and South Atlantic, North, tropical and South Pacific, 390 to 3950 fathoms.
Webbina clavata—North, tropical and South Atlantic, Mediterranean, North, tropical and South Pacific, 90 to 2000 fathoms.
Cyclammina cancellata—North, tropical and South Atlantic, Magellan Strait, Mediterranean, North, tropical and South Pacific, 75 to 2900 fathoms.
„ *pusilla*—North, tropical and South Atlantic, North Pacific, 390 to 2050 fathoms.
Textularia concava—North, tropical and South Atlantic, Magellan Strait, tropical and South Pacific, 17 to 2750 fathoms.
Verneuilina pygmæa—North, tropical and South Atlantic, North, tropical and South Pacific, 129 to 3125 fathoms.
Gaudryina pupoides—North, tropical and South Atlantic, North, tropical and South Pacific, 129 to 2425 fathoms.
Clavulina communis—North, tropical and South Atlantic, Magellan Strait, North, tropical and South Pacific, 147 to 2300 fathoms.
Bulimina aculeata—North, tropical and South Atlantic, North, tropical and South Pacific, shallow water to 2740 fathoms.
„ *marginata*—North, tropical and South Atlantic, Magellan Strait, North, tropical and South Pacific, shallow to 1630 fathoms.
„ *rostrata*—North, tropical and South Atlantic, tropical Pacific, 580 to 1570 fathoms.
„ *subteres*—Arctic, North, tropical and South Atlantic, North, tropical and South Pacific, 28 to 1875 fathoms.
Virgulina schreibersiana—Cosmopolitan, 10 to 3000 fathoms.
„ *squamosa*—Cosmopolitan, 30 to 3000 fathoms.
„ *subdepressa*—North, tropical and South Atlantic, North and South Pacific, 1375 to 2350 fathoms.
Bolivina punctata—Cosmopolitan, 2 to 2750 fathoms.
Cassidulina bradyi—North and tropical Atlantic, Magellan Strait, North, tropical and South Pacific, 90 to 2050 fathoms.
„ *crassa*—Cosmopolitan, 40 to 2760 fathoms.
„ *lævigata*—Cosmopolitan, 60 to 1600 fathoms.
„ *subglobosa*—North, tropical and South Atlantic, North, tropical and South Pacific, 12 to 2950 fathoms.
Ehrenbergina serrata—North, tropical and South Atlantic, North, tropical and South Pacific, 150 to 2350 fathoms.
Lagena acuta—Cosmopolitan, 2 to 3125 fathoms.
„ *acuticosta*—Cosmopolitan, shore to 2750 fathoms.
„ *alveolata*—North and South Atlantic, North, tropical and South Pacific, 150 to 2740 fathoms.

Lagena apiculata—Cosmopolitan, shore to 2750 fathoms.
„ *auriculata*—North, tropical and South Atlantic, North, tropical and South Pacific, 620 to 2750 fathoms.
„ *clavata*—Cosmopolitan, shore to 2435 fathoms.
„ *distoma*—North, tropical and South Atlantic, Magellan Strait, North, tropical and South Pacific, shallow to 1900 fathoms.
„ *exsculpta*—North and South Atlantic, North, tropical and South Pacific, 800 to 2600 fathoms.
„ *feildeniana*—Arctic, North and South Atlantic, North, tropical and South Pacific, 45 to 2300 fathoms.
„ *fimbriata*—North Atlantic, North, tropical and South Pacific, 580 to 2300 fathoms.
„ *formosa*—North, tropical and South Atlantic, North, tropical and South Pacific, 50 to 2750 fathoms.
„ *globosa*—Cosmopolitan, shore to over 3000 fathoms.
„ *gracilis*—Cosmopolitan, shallow water to 2775 fathoms.
„ *gracillima*—Cosmopolitan, shallow water to 2300 fathoms.
„ *hertwigiana*—North Atlantic, tropical Pacific, 150 to 200 fathoms.
„ *hexagona*—Cosmopolitan, shallow water to 2300 fathoms.
„ *interrupta*—Cosmopolitan, shore to 2750 fathoms.
„ *lævigata*—Cosmopolitan, 2 to 3125 fathoms.
„ *lævis*—Cosmopolitan, shore to 2435 fathoms.
„ *longispina*—Cosmopolitan, 1070 to 2740 fathoms.
„ *marginata*—Cosmopolitan, shore to 3125 fathoms.
„ *orbignyana*—Cosmopolitan, shallow water to over 3000 fathoms.
„ *quadricostulata*—Tropical and South Atlantic, North, tropical and South Pacific, 410 to 2325 fathoms.
„ *semistriata*—Cosmopolitan, shore to 2750 fathoms.
„ *squamosa*—Cosmopolitan, shallow water to 2300 fathoms.
„ *staphyllearia*—North, tropical and South Atlantic, North, tropical and South Pacific, shallow to 2750 fathoms.
„ *stelligera*—North, tropical and South Atlantic, North, tropical and South Pacific, 20 to 2740 fathoms.
„ *striata*—Cosmopolitan, shallow water to 2600 fathoms.
„ *sulcata*—Cosmopolitan, shore to 2750 fathoms.
„ *truncata*—North, tropical and South Atlantic, tropical and South Pacific, 1825 to 2740 fathoms.
Nodosaria calomorpha—North, tropical and South Atlantic, tropical Pacific, 6 to 2200 fathoms.
„ *communis*—Cosmopolitan, shore to 3000 fathoms.
„ *mucronata*—North, tropical and South Atlantic, Mediterranean, North, tropical and South Pacific, shallow to 2600 fathoms.
„ *obliqua*—Cosmopolitan, shallow water to 2000 fathoms.
„ *roemeri*—Cosmopolitan, shore to 3000 fathoms.
„ (*Glandulina*) *lævigata*—Cosmopolitan, 7 to 1360 fathoms.
„ („) *rotundata*—Cosmopolitan, 7 to 1360 fathoms.
Marginulina costata—North, tropical and South Atlantic, Mediterranean, South Pacific, shallow to 2350 fathoms.
Vaginulina legumen—Cosmopolitan, shallow water to over 2000 fathoms.
„ *linearis*—North, tropical and South Atlantic, shallow water to 435 fathoms.
Cristellaria convergens—North, tropical and South Atlantic, North, tropical and South Pacific, 16 to 2740 fathoms.
„ *crepidula*—Arctic, North and tropical Atlantic, North, tropical and South Pacific, 6 to 2350 fathoms.
„ *cultrata*—Cosmopolitan, shallow water to 2435 fathoms.
Polymorphina angusta—North, tropical and South Atlantic, North, tropical and South Pacific, shallow to 2400 fathoms.
„ *lanceolata*—North, tropical and South Atlantic, North, tropical and South Pacific, shallow to 2350 fathoms.
„ *sororia*—Cosmopolitan, shallow water to 2350 fathoms.
Uvigerina angulosa—Cosmopolitan, 8 to 1630 fathoms.
„ *asperula*—North, tropical and South Atlantic, North, tropical and South Pacific, 37 to 2600 fathoms.
„ *pygmæa*—Cosmopolitan, 2 to 2600 fathoms.
„ *tenuistriata*—North and South Atlantic, Magellan Strait, North, tropical and South Pacific, 40 to 2600 fathoms.
Sagrina raphanus—North and tropical Atlantic, Indian Ocean, North, tropical and South Pacific, shore to 260 fathoms.
Globigerina bulloides—Cosmopolitan, surface and bottom at all depths.
„ *dubia*—North, tropical and South Atlantic, North, tropical and South Pacific, surface and bottom.
„ *dutertrei*—North and tropical Atlantic, South Pacific, surface and bottom.
„ *inflata*—Cosmopolitan, surface and bottom.
Orbulina universa—Cosmopolitan, surface and bottom.
Pullenia obliquiloculata—North, tropical and South Atlantic, North, tropical and South Pacific, surface and bottom.
„ *quinqueloba*—Cosmopolitan, 20 to 2750 fathoms.
„ *sphæroides*—Cosmopolitan, shallow water to 2750 fathoms.
Sphæroidina bulloides—Cosmopolitan (except Arctic), 37 to 2600 fathoms.

Spirillina decorata—North, tropical and South Atlantic, tropical Pacific, 6 to 1900 fathoms.
„ *limbata*—North, tropical and South Atlantic, Mediterranean, North, tropical and South Pacific, 6 to 1425 fathoms.
„ *tuberculata*—North Atlantic, Magellan Strait, Indian Ocean, tropical Pacific, shallow to 400 fathoms.
„ *vivipara*—Cosmopolitan, shallow water to 620 fathoms.
Patellina corrugata—Arctic, North and South Atlantic, Mediterranean, Indian Ocean, tropical and South Pacific, 2 to 620 fathoms.
Discorbina araucana—Cosmopolitan (except Arctic), shallow water to 1375 fathoms.
„ *rosacea*—Cosmopolitan (except Arctic), shallow water to 1000 fathoms.
„ *vilardeboana*—Cosmopolitan (except Arctic), shallow water.
Truncatulina akneriana—Cosmopolitan, shore to 3000 fathoms.
„ *haidingerii*—Cosmopolitan (except Arctic), 9 to 1776 fathoms.
„ *lobatula*—Cosmopolitan, shore to 3000 fathoms.
„ *pygmæa*—North, tropical and South Atlantic, North, tropical and South Pacific, 1450 to 3125 fathoms.
„ *tenera*—North, tropical and South Atlantic, Magellan Strait, North, tropical and South Pacific, 166 to 2050 fathoms.
„ *ungeriana*—North, tropical and South Atlantic, Mediterranean, North, tropical and South Pacific, 37 to 2600 fathoms.
„ *wuellerstorfi*—North, tropical and South Atlantic, North, tropical and South Pacific, 210 to 2435 fathoms.
Anomalina grosserugosa—North, tropical and South Atlantic, North, tropical and South Pacific, 345 to 2160 fathoms.
Pulvinulina crassa—North, tropical and South Atlantic, North, tropical and South Pacific, surface and bottom.
„ *elegans*—North, tropical and South Atlantic, North, tropical and South Pacific, shore to 2000 fathoms.
„ *exigua*—North, tropical and South Atlantic, North, tropical and South Pacific, 64 to 2740 fathoms.
„ *micheliniana*—Cosmopolitan, 15 to 2950 fathoms; taken at the surface in tropical and South Atlantic, North, tropical and South Pacific.
„ *patagonica*—North, tropical and South Atlantic, North, tropical and South Pacific, 90 to 2900 fathoms; taken at the surface in South Atlantic and Magellan Strait.
„ *pauperata*—North, tropical and South Atlantic, tropical and South Pacific, 129 to 2350 fathoms.
„ *umbonata*—North, tropical and South Atlantic, North, tropical and South Pacific, 37 to 3125 fathoms.
Rotalia orbicularis—Cosmopolitan (except Arctic), 100 to 2400 fathoms.
„ *soldanii*—Cosmopolitan (except Arctic), 100 to over 2000 fathoms.
Nonionina depressula—Cosmopolitan, shallow water to 2740 fathoms.
„ *pompilioides*—North, tropical and South Atlantic, Mediterranean, North, tropical and South Pacific, 1000 to 2750 fathoms.
„ *umbilicatula*—Cosmopolitan, 30 to 3125 fathoms.
Polystomella crispa—Cosmopolitan, shore to 355 fathoms.
„ *macella*—North, tropical and South Atlantic, Indian Ocean, tropical and South Pacific, shallow water.
„ *striatopunctata*—Cosmopolitan, shallow water to over 2000 fathoms.

It will be noticed that there is an important difference in the geographical and bathymetrical distribution of this group of Protozoa from what obtains in the case of the Metazoa considered in the previous lists. 179 species or 82 per cent. of the total number recorded from the Kerguelen Region have also been found within the tropics and in the extra-tropical regions of the Northern Hemisphere, and the majority of these species have a wide range in depth. The peculiar habits of the group as well as its antiquity possibly explain this distribution.

LIST VII*f*.

Looking upon the distribution of varieties as distinct from that of the species to which they belong, the following shows the distribution outside this area of the 8 varieties represented in the area under consideration :—

Biloculina depressa, var. *murrhyna*—North, tropical and South Atlantic, North, tropical and South Pacific, 1100 to 2425 fathoms.
„ „ var. *serrata*—North and tropical Atlantic, North, tropical and South Pacific, 580 to 2350 fathoms.

Articulina funalis, var. *inornata*—Known only from this area.
Lagena alveolata, var. *substriata*—South Atlantic, tropical and South Pacific, 150 to 2350 fathoms.
„ *formosa*, var. *favosa*—Tropical Pacific, 1850 fathoms.
„ *marginata*, var. *semimarginata*—North, tropical and South Atlantic, tropical and South Pacific, 50 to 2600 fathoms.
Polymorphina sororia, var. *cuspidata*—North Atlantic, 808 to 1443 fathoms.
Globigerina bulloides, var. *triloba*—Cosmopolitan, surface and bottom.

The distribution of these species of Foraminifera may be summarised thus :—

Geographical Distribution.—It will be observed that no fewer than 71 species (or 32 per cent. of the total number) are cosmopolitan, and that other 8 species (or 4 per cent.) are almost cosmopolitan, having a world-wide distribution, except that they have not yet been recorded from the Arctic regions. The remaining species are distributed among the various regions of the oceans as follows :—

111	species	(or 50 per cent.)	are represented in the	North Atlantic.
94	„	(„ 43 „)	„	Tropical Pacific.
94	„	(„ 43 „)	„	South Pacific.
93	„	(„ 42 „)	„	South Atlantic.
87	„	(„ 40 „)	„	Tropical Atlantic.
81	„	(„ 37 „)	„	North Pacific.
14	„	(„ 6 „)	„	Magellan Strait.
13	„	(„ 6 „)	„	Mediterranean.
8	„	(„ 4 „)	„	Arctic.
7	„	(„ 3 „)	„	Indian Ocean (including Red Sea).

Bathymetrical Distribution.—It appears that a total of 178 species (or 81 per cent. of the total number) occur both in deep water over 1000 fathoms and in lesser depths, while 14 species (or 6 per cent.) are known only from deep water over 1000 fathoms, and 14 species (or 6 per cent.) are known only from depths less than 1000 fathoms; 147 species (or 67 per cent.) occur in shallow water under 150 fathoms.

LIST VII*g*.

The following are the 14 species known only from deep water over 1000 fathoms :—

Keramosphæra murrayi.
Astrorhiza granulosa.
Aschemonella ramuliformis.
Reophax cylindrica.
Haplophragmium rotulatum.
Thurammina albicans.
Hormosina ovicula.
Cyclammina orbicularis.
Virgulina subdepressa.
Lagena longispina.
Lagena quadralata.
„ *truncata.*
Truncatulina pygmæa.
Nonionina pompilioides.

LIST VII*h*.

The following are the 14 species known only from depths under 1000 fathoms, of which 6 species are known only from shallow water under 150 fathoms as indicated :—

Nubecularia inflata.
Miliolina subrotunda (shallow).
Articulina funalis.
Reophax ampullacea (shallow).
Sagrina raphanus.
Spirillina obconica (shallow).
„ *tuberculata.*
„ *vivipara.*
Patellina corrugata.
Discorbina parisiensis (shallow).
Discorbina rosacea.
„ *vilardeboana* (shallow).
Polystomella crispa.
„ *macella* (shallow).

LIST VIII.

Radiolaria observed in the Deposit and at the Surface at the Challenger Station 157 in the Southern Indian Ocean.

The following is a list of the species of Radiolaria (numbering 81 species, belonging to 63 genera) observed in the deposit from the Challenger deep-water Station 157, lat. 53° 55′ S., 1950 fathoms, in the Southern Indian Ocean.

The sediment which remains after removing the Diatoms and Foraminifera and larger mineral particles is almost entirely composed of Radiolarians, mainly belonging to a few species of Sphæroidea which make up about nine-tenths of the whole mass. By far the commonest of these Spumellaria is *Cromyosphæra antarctica*, which is probably genetically related with the very similar form, *Cromyomma perspicuum*, occurring on the surface at the same Station. Of the other Spumellaria the Discoidea are the most abundant, particularly the spongy forms (Spongodiscida, *e.g.*, *Spongodiscus*, *Spongotrochus*, *Stylotrochus*). Particularly noteworthy is a new genus, *Spongopyle*, not described in the Challenger Report; it is a Spongodiscid with a marginal osculum like that of the Porodiscid *Ommatodiscus*, which also occurs at this Station. In contrast to the large number of Sphæroidea and Discoidea, the Prunoidea and Larcoidea are present only as isolated specimens.

Very few species of Nassellaria are present, but among them the Botryodea, which are generally rare, are rather abundant, especially *Botryocella borealis* and *Botryopyle cribrosa*. The most common Cyrtoidea are a few cosmopolitan forms, for example, *Cornutella clathrata*, *Cornutella cannulata*, and *Lithomitra lineata*.

The Acantharia are only represented in this deposit by a single rare species, *Pantopelta icosaspis*.

The Phæodaria are represented by a few remarkable forms, such as *Sagenoscena penicillata*, *Aulosphæra bisternaria*, *Cannosphæra antarctica*, and *Conchasma hippurites*; all these, however, are rare.

I. Spumellaria.

a. Sphæroidea.

Cenosphæra solida, Haeckel.
„ *papillata*, Haeckel.
„ *antiqua*, Haeckel.
„ *antarctica*, Haeckel.
Carposphæra nobilis, Ehrenberg.
Thecosphæra diplococcus, Haeckel.
Cromyosphæra antarctica, Haeckel.
Styptosphæra spongiacea, Haeckel.
Spongoplegma antarcticum, Haeckel.
Spongodictyon antarcticum, Haeckel.
Amphisphæra neptunus, Haeckel.
Stauracontium antarcticum, Haeckel.
Hexacontium hexaconicum, Haeckel.
„ *antarcticum*, Haeckel.
Acanthosphæra antarctica, Haeckel.
Cladococcus antarcticus, Haeckel.
„ *dendrites*, Haeckel.
Haliomma antarcticum, Haeckel.
Actinomma pachycapsa, Haeckel.

Pityomma piniferum, Haeckel.
Cromyomma perspicuum, Haeckel.
Rhizosphæra trigonacantha, Haeckel.
„ *antarctica*, Haeckel.

b. Prunoidea.

Cromyocarpus quadrifarius, Haeckel.
Cromyatractus tetraphractus, Haeckel.
Spongurus cylindricus, Haeckel.
Spongocora cincta, Haeckel.

c. Discoidea.

Porodiscus flustrella, Haeckel.
„ *heterocyclus*, Haeckel.
„ *spiralis* (Ehrenberg).
Ommatodiscus stöhrii, Haeckel.
„ *lævigatus*, Stöhr.
Stylodictya multispina, Haeckel.
Rhopalastrum irregulare, Haeckel.
Euchitonia muelleri, Haeckel.
Spongodiscus resurgens, Ehrenberg.
„ *spiralis*, Haeckel.
Spongopyle osculosa, Haeckel.
„ *setosa*, Haeckel.
Stylotrochus antarcticus, Haeckel.
„ *challengeri*, Haeckel.
Spongotrochus murrayi, Haeckel.
„ *wyvillei*, Haeckel.
„ *moseleyi*, Haeckel.
„ *willemoesii*, Haeckel.
„ *scutella*, Haeckel.

d. Larcoidea.

Stypolarcus spongiosus, Haeckel.
Larcospira oliva, Haeckel.

II. Acantharia.

Pantopelta icosaspis, Haeckel.

III. Nassellaria.

a. Plectoidea.

Hexaplagia antarctica, Haeckel.

b. Spyroidea.

Tripospyris eucolpos, Haeckel.
Dictyospyris tetrastoma, Ehrenberg.
„ *enneastoma*, Haeckel.

c. Botryodea.

Androspyris aptenodytes, Haeckel.
Botryocella borealis, Ehrenberg.
Botryopyle cribrosa (Ehrenberg).
Botryocyrtis quinaria, Ehrenberg.
Botryocampe inflata, Ehrenberg.

d. Cyrtoidea.

Cyrtocalpis ovulum, Haeckel.
Cornutella clathrata, Ehrenberg.
„ *annulata*, Ehrenberg.
Cornutanna orthoconus, Haeckel.
Halicapsa hystrix, Haeckel.
Dictyocephalus antarcticus, Haeckel.
Dicolocapsa megacephala, Haeckel.
Dictyophimus antarcticus, Haeckel.
Theocorys plutonis, Haeckel.
Lithostrobus bicornis, Haeckel.
„ *cornutella*, Butschli.
Theocalyptra cornuta (Ehrenberg).
Lithomitra lineata (Ehrenberg).
Eucyrtidium chrysalidium, Haeckel.

IV. Phæodaria.

Aulactinium actinosphærium, Haeckel.
Sagenoscena penicillata, Haeckel.
Aulosphæra bisternaria, Haeckel.
Aulastrum dichoceros, Haeckel.
Aulodictyum hydrodictyum, Haeckel.
Cannosphæra antarctica, Haeckel.
Challengeria naresii, Murray.
„ *trifida*, Haeckel.
Conchasma hippurites, Haeckel.

Of the 81 species enumerated, 57 species (or 70 per cent.) are not recorded in the Challenger Report from any other locality, while 21 species (or 26 per cent.) are represented in the tropical Pacific (11 species both at the surface and bottom, 7 species at the bottom only, and 3 species at the surface only), 3 species are represented in the South Atlantic (2 at the surface and 1 at the bottom), 2 species are recorded from the bottom in the tropical Atlantic (West Indies), and 1 species each from the bottom in the North Pacific and South Pacific respectively.

Two species (*Cenosphæra papillata* and *Thecosphæra diplococcus*) occur outside this

area both in the South Atlantic and tropical Pacific, while another species (*Cenosphæra antiqua*) occurs both in the tropical and South Atlantic and tropical Pacific. The remainder of the species occurring outside this area are each represented in a single region of the ocean, as indicated above.

LIST VIII *a*.

The following species of Radiolaria were observed in the surface gatherings taken by the Challenger in the Southern Indian Ocean (Station 157, lat. 53° 55′ S.). Of the 24 species enumerated, one-half (*i.e.*, the 12 species of Spumellaria and Nassellaria) were observed also in the bottom-deposit at the same Station, of which 5 species (*Styptosphæra spongiacea*, *Cromyomma perspicuum*, *Rhizosphæra trigonacantha*, *Porodiscus flustrella*, and *Cyrtocalpis ovulum*) occur also in the tropical Pacific. Of the 12 species of Acantharia and Phæodaria (the skeletons of which apparently pass into solution before, or immediately after, reaching the bottom), 4 species are recorded from other regions, but, curiously enough, only from the Atlantic (while, as stated above, the 5 species of Spumellaria and Nassellaria occurring outside this area are recorded only from the tropical Pacific), viz., *Acanthostaurus purpurascens* recorded from the surface in the North and tropical Atlantic, *Challengeron balfouri* recorded from the surface in the North Atlantic, and *Dictyocha stapedia* and *Distephanus speculum* recorded from the bottom in the tropical Atlantic (West Indies, 450 fathoms).

In striking contrast to the wealth of forms in the deposit at this Station is the uniformity of the Radiolarian surface fauna. This, doubtless, arises from the fact that the tow-nets were only dragged through a relatively small distance of the surface waters, whereas the deposit at the bottom represents the accumulation of forms which have fallen from the surface during an immense period of time. The absence of some species of Acantharia and Phæodaria in the deposit, when compared with their relative abundance in the surface-net gatherings, is to be accounted for by the structure and composition of the skeletons, which are more readily dissolved after the death of the animals. Certain species of Acantharia and Phæodaria are the most abundant on the surface, and these are very rich in individuals. Of the Acantharia the most abundant are *Acanthonia claparedei*, *Acanthostaurus purpurascens*, and *Amphilonche lanceolata*, and of the Phæodaria the species of *Challengeron*.

I. Spumellaria.

a. Sphæroidea.

Styptosphæra spongiacea, Haeckel.
Acanthosphæra antarctica, Haeckel.
Cromyomma perspicuum, Haeckel.
Rhizosphæra trigonacantha, Haeckel.
,, *antarctica*, Haeckel.

b. Discoidea.

Porodiscus flustrella, Haeckel.
Stylodictya multispina, Haeckel.
Euchitonia muelleri, Haeckel.
Stylotrochus challengeri, Haeckel.

II. Acantharia.

Acanthonia claparedei, Haeckel.
Acanthostaurus purpurascens, Haeckel.

Amphilonche lanceolata, Haeckel.
Porocapsa coronodon, Haeckel.

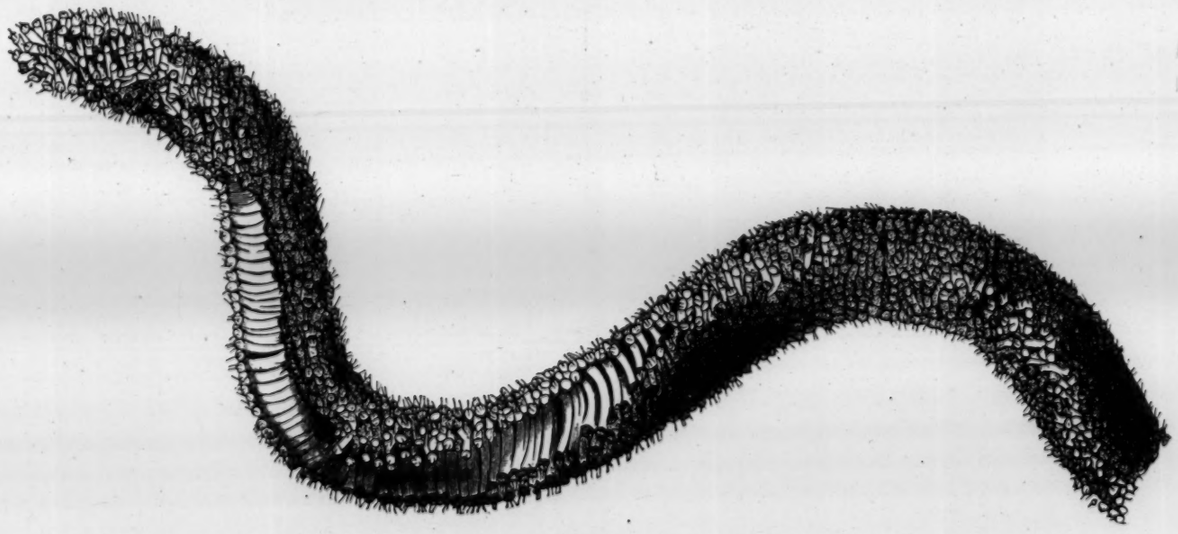
III. NASSELLARIA.

Dictyospyris tetrastoma, Ehrenberg.
Cyrtocalpis ovulum, Haeckel.
Cornutella clathrata, Ehrenberg.

IV. PHÆODARIA.

Dictyocha stapedia, Haeckel.
Distephanus speculum, Haeckel.
Aulodendron antarcticum, Haeckel.
Auloscena penicillus, Haeckel.
Challengeron pearceyi, Haeckel.
„ *swirei*, Murray.
„ *balfouri*, Murray.
„ *richardsii*, Haeckel.

It may be pointed out that the species collected from the surface and bottom at this Station are much fewer than at many tropical Stations; for instance, at a Station in the Central Pacific, just under the equator, 379 species of Radiolaria were observed in the surface gatherings, and 550 species in the deposit at the bottom.



Callozostron mirabilis, Wright. Discovered by the Challenger in the deep-water area of the Kerguelen Region.

LIST IX.

Diatomaceæ observed in the Deposits and at the Surface in the Kerguelen Region.

Although it was proposed to limit the scope of this paper to the *fauna* of the Kerguelen Region, it has been deemed desirable to include a list of the Diatoms observed in the deposits and captured at the surface. The following is a list of the Diatoms observed in the deposits from the Kerguelen Region of the Southern Ocean, viz., at Station 145 (Marion Island), 85 to 140 fathoms; Station 149 (Kerguelen), 20 to 120 fathoms; Station 151 (Heard Island), 75 fathoms; and Station 157, 1950 fathoms:—

Amphora angusta, Gregory.
„ *cuneata*, Cleve.
„ *plicata*, Gregory.
„ *proteus*, Gregory.
Navicula apis, Donkin.
„ *arenaria*, Donkin.
„ *aspera*, Ehrenberg, var. *oblonga*, Cleve.
„ „ „ var. *rhombica*, Cleve.
„ *brasiliensis*, Grunow.
„ *consors*, A. Schmidt.
„ *constricta*, Grunow.
„ *distans*, Ralfs.
„ *firma*, Kutzing, var. *tumescens*.
„ *gemmata*, Greville, var. *minuta*.
„ *jejuna*, A. Schmidt.
„ *multicostata*, Grunow.
„ *nitescens*, Gregory.
„ *oscitans*, A. Schmidt, var. *subundulata*, Cleve and Grunow.
„ *rhomboides*, Ehrenberg.
„ *smithii*, Brebisson.
„ *serians*, Brebisson.
„ *splendida*, Gregory.
„ *subtilis* (Gregory).
„ *viridis*, Ehrenberg.
Rhoikoneis bolleana, Grunow.
Pleurosigma delicatulum, Smith.
„ *directum*, Cleve.
„ *kerguelense*, Grunow.
„ *rigidum*, Smith.
Rhoikosigma arcticum, Cleve.
Amphiprora duplex, Donkin.
„ *kriophila*.
„ *lepidoptera*, Gregory.

Cocconeis arctica, Grunow.
„ *costata*, Gregory.
„ „ var. *kerguelensis*, Petit.
„ *cyclophora*, Grunow.
„ *decipiens*, Cleve.
„ *dirupta*, Gregory, var. *fulgur*, Brun.
„ „ var. *minutissima*, Grunow.
„ „ var. *sigma*, Pant.
„ *scutellum*, Ehrenberg.
„ „ var. *ampliata*, Grunow.
„ „ var. *distans*, Grunow.
„ „ var. *fulgur*, Cleve.
„ „ var. *minutissima*, Grunow.
„ sp. (?).
Orthoneis wrightii (O'Meara).
Achnanthes brevipes, Agardh.
„ „ var. *subsessilis*.
„ *parvula*, Kutzing.
Gephyria gigantea, Greville.
„ *incurvata*, Arn.
Thalassiothrix longissima, Grunow, var. *antarctica*, Cleve and Grunow.
„ *nitzschioides*, Grunow.
„ „ var. *lanceolata*, Grunow.
„ *nordenskioldii*, Cleve.
Nitzschia apiculata, Smith.
„ *constricta*, Gregory, var. *antarctica*, Rattray.
„ „ var. *similis*, Grunow.
„ *distans*, Gregory.
„ *insignis*, Gregory.
„ *marina*, Grunow.
Synedra filiformis, Grunow.
„ *lanceolata*, Castracane.
„ sp. (?).

Trachysphenia australis, Petit.
„ „ var. *antarctica* (Schwarz).
Clavicula delicata, Temp. and Brun.
Licmophora australis, Grunow.
„ *californica*, Grunow.
„ *jurgensii*, Grunow.
Fragilaria capensis, Grunow.
„ *dubia*, Grunow.
„ *linearis*, Castracane.
„ *pliocena*, Brun.
„ (?) an *Terebraria* (?) sp.
Grammatophora angulosa, Ehrenberg, var. *hamulifera*.
„ „ var. *islandica*.
„ *marina*, Kutzing.
„ *maxima*, Grunow, var. *genuina*.
„ *oceanica*, Ehrenberg.
„ *stricta*, Ehrenberg.
„ *subundulata*, Grunow.
Biddulphia roperiana, Greville.
„ *weissflogii*, Grunow.
Isthmia enervis, Ehrenberg.
Hemiaulus antarcticus, Ehrenberg.
Triceratium antediluvianum, Heurck.
„ *arcticum*, Brightwell, var. *kerguelensis*, Grunow.
Hemidiscus cuneiformis, Wallich.
„ sp. (?).
Auliscus cœlatus, Bailey.
Coscinodiscus africanus, Janisch.
„ „ var. *wallichiana*, Grunow.
„ *antarcticus*, Grunow.
„ *apollinis*, Ehrenberg, var. *compacta*, Rattray.
„ *asteromphalus*, Ehrenberg.
„ *atlanticus*, Castracane.
„ *centralis*, Ehrenberg.
„ *concinnus*, Smith.
„ „ var. *kerguelensis*, Castracane.
„ *convexus*, A. Schmidt.
„ *curvatulus*, Grunow.
„ „ var. *elegans*, Rattray.
„ „ var. *genuina*, Grunow.
„ „ var. *maculata*, Rattray.
„ „ var. *recta*, Rattray.
„ „ var. *subocellata*, Grunow.
„ *decrescens*, Grunow, var. *polaris*, Grunow.
„ „ var. *repleta*, Grunow.
„ *denarius*, A. Schmidt.
„ *denticulatus*, Castracane.
„ *elegans*, Greville.
„ *elegantulus*, Greville.
„ *excentricus*, Ehrenberg.
„ „ var. *sublineatus*, Grunow.
Coscinodiscus fasciculatus, A. Schmidt.
„ *grandis*, Rattray.
„ „ var. *sparsa*, Rattray.
„ *griseus*, Greville, var. *gallopagensis*, Grunow.
„ *impolitus*, Rattray.
„ *kutzingii*, A. Schmidt, var. *glacialis*, Grunow.
„ *lentiginosus*, Janisch.
„ „ var. *maculata*, Grunow.
„ *lineatus*, Ehrenberg.
„ *lunæ*, Ehrenberg.
„ *margaritaceus*, Castracane.
„ *marginatus*, Ehrenberg.
„ *minor*, Ehrenberg.
„ *mölleri*, A. Schmidt, var. *antarctica*, Rattray.
„ *nodulifer*, A. Schmidt.
„ *normanni*, Gregory.
„ *oculus-iridis*, Ehrenberg.
„ *perforatus*, Ehrenberg, var. *cellulosa*, Grunow.
„ *radiatus*, Ehrenberg.
„ *radiosus*, Grunow.
„ „ var. *kerguelensis*, Grunow.
„ *robustus*, Greville.
„ „ var. *minor*, Rattray.
„ *rothii*, Grunow.
„ *rotula*, Grunow.
„ *stellaris*, Roper.
„ *subtilis*, Ehrenberg.
„ „ var. *glacialis*, Grunow.
„ *symbolophorus*, Grunow.
„ *tuberculatus*, Greville, var. *antarctica*, Rattray.
„ „ var. *excentrica*, Rattray
„ *tumidus*, Janisch.
„ „ var. *fasciculata*, Rattray.
Hyalodiscus radiatus, Petit.
„ „ var. *arctica*, Grunow.
„ *subtilis*, Ehrenberg.
Podosira hormoides, Kutzing.
„ *maxima*, Kutzing.
„ *montaguei*, Kutzing.
Cyclotilla castracanei, Brun.
Melosira arenaria, Moore.
„ *borreri*, Greville.
„ *sol*, Kutzing.
„ sp. (?).
Actinocyclus oliverianus, O'Meara.
Actinoptychus campanulifer, A. Schmidt.
„ sp. (?).
Asteromphalus antarcticus, Castracane.

Asteromphalus brookei, Bailey.
„ *darwinii*, Ehrenberg.
„ *hookerii* (Ehrenberg), Ralfs.
„ „ forma *buchii* (Ehrenberg).
„ „ forma *cuvierii* (Ehrenberg).
„ „ forma *denarius* (Janisch).
„ „ forma *humboldtii* (Ehrenberg).
Rhabdonema adriaticum, Kutzing.
„ *minutum*, Kutzing.
Paralia sulcata, Cleve.
Stephanopyxis turris, Ralfs, var. *inermis*, Grunow.
Rhizosolenia furcata, Rattray.
„ *hastata*, Grunow.
„ *setigera*, Brightwell.
„ *styliformis*, Brightwell.
Stauroneis phenicenteron, Ehrenberg.
Epithemia sp. (?).
Tabellaria fenestrata, Kutzing.
Chætoceros dicladia, Castracane, and its sporangial form *Dicladia capreolus*, Ehrenberg.
Diatoma rhombicum, O'Meara, var. *oceanica*, Rattray.
Corethron criophilum, Castracane.
Brunia mirabilis, Tempère.

LIST IX *a*

The following 25 species were found in the deposits from both deep and shallow-water, viz. :—

Thalassiothrix longissima.
„ *nitzschioides.*
Nitzschia constricta.
Trachysphenia australis.
Biddulphia weissflogii.
Hemiaulus antarcticus.
Triceratium arcticum.
Hemidiscus cuneiformis.
Coscinodiscus africanus.
„ *atlanticus.*
„ *centralis.*
„ *concinnus.*
„ *convexus.*
Coscinodiscus curvatulus.
„ *denarius.*
„ *excentricus.*
„ *kutzingii.*
„ *lentiginosus.*
„ *lineatus.*
„ *radiatus.*
„ *tumidus.*
Hyalodiscus radiatus.
Actinocyclus oliverianus.
Asteromphalus hookerii.
„ *brookei.*

LIST IX *b*.

The following is a list of the Diatoms observed in the surface gatherings procured by the Challenger in the Southern Indian Ocean (Station 157, lat. 53° 55′ S.) :—

Navicula aspera, Ehrenberg.
„ *subtilis* (Gregory).
Pleurosigma antarcticum, Grunow.
Amphiprora antarctica, Grunow.
Synedra lanceolata, Castracane.
Nitzschia scalaris, W. Smith.
Thalassiothrix longissima, Grunow, var. *antarctica*, Cleve and Grunow.
Trachysphenia australis, Petit, var. *antarctica* (Schwarz).
Fragilaria (?) an *Terebraria* (?) sp.
Rhizosolenia indica, Peragallo.
„ *inermis*, Castracane.
„ *setigera*, Brightwell.
„ *styliformis*, Brightwell.
Dactyliosolen antarcticus, Castracane.
Melosira sp. (?).
Chætoceros antarcticum, Grunow.
„ *atlanticum*, Cleve.
„ „ var. *attenuata*, Cleve and Grunow.
„ *boreale*, var. *brightwellii*, Cleve.
„ *decipiens*, Cleve.
„ *dispar*, Castracane.
„ *remotum*, Cleve and Grunow.
„ „ var. *biaurita*, Rattray.
„ „ var. *robusta*, Rattray.
„ *sigmoidea*, Rattray.
„ *tetrachæta*, Ehrenberg.
Corethron criophilum, Castracane.
„ „ var. *tumescens*, Rattray.
„ *hispidum*, Castracane.
„ *murrayanum*, Castracane.
„ *pennatum* (Grunow).

Corethron splendens, Rattray.
Hemiaulus antarcticus, Ehrenberg.
Actinocyclus oliverianus, O'Meara.
„ „ forma *minor*.
Asteromphalus brookei, Bailey.
„ *hookerii*, Ehrenberg.
Bacteriastrum varians, Lauder.
Coscinodiscus africanus, Janisch, var. *wallichiana*, Grunow.
„ *anguste-lineatus*, A. Schmidt.
„ *convexus*, A. Schmidt.
Coscinodiscus denarius, A. Schmidt.
„ *excentricus*, Ehrenberg.
„ *kutzingii*, A. Schmidt, var. *glacialis*, Grunow.
„ *lentiginosus*, Janisch.
„ *lineatus*, Ehrenberg.
„ *lunæ*, Ehrenberg.
„ *margaritaceus*, Castracane.
„ *oculus-iridis*, Ehrenberg.
„ *subtilis*, Ehrenberg.
„ *tumidus*, Janisch.

LIST IX *c*.

The following 26 species occur both in the surface gatherings and in the deposits at the bottom within this region :—

Navicula aspera.
„ *subtilis*.
Synedra lanceolata.
Thalassiothrix longissima.
Trachysphenia australis.
Fragilaria (?) an *Terebraria* (?) sp.
Rhizosolenia setigera.
„ *styliformis*.
Melosira sp. (?).
Corethron criophilum.
Hemiaulus antarcticus.
Actinocyclus oliverianus.
Asteromphalus brookei.
Asteromphalus hookerii.
Coscinodiscus africanus.
„ *convexus*.
„ *denarius*.
„ *excentricus*.
„ *kutzingii*.
„ *lentiginosus*.
„ *lineatus*.
„ *lunæ*.
„ *margaritaceus*.
„ *oculus-iridis*.
„ *subtilis*.
„ *tumidus*.

The following general remarks on the Diatoms observed in the surface gatherings and in the deposit from the Challenger deep-water Station 157, extracted from the Challenger Report, Summary of Results, pp. 513–514, may be of interest :—

Considerable differences are recognisable between the general appearance of Diatom preparations made from surface gatherings as contrasted with those procured from the ooze forming the bottom in this locality. By far the most abundant form at the surface was the peculiar, very elongated, flexuous *Thalassiothrix longissima*, var. *antarctica*, Cleve and Grunow [=*Synedra thalassiothrix*, Cleve *in parte*], a species which has already been recorded as forming large floating masses in the Arctic Ocean.[1] In the Antarctic its frustules were found arranged in little bundles—from ten to twelve together—fastened together loosely at one end, but separate at the other, the whole being loosely twisted into a spindle. In preparations isolated frustules of it occur but rarely, often two are found closely apposed, but not uncommonly three, four, or even more are so placed. It is, perhaps, with *Chætoceros remotum*, Cleve and Grunow [=*C. janischianum*, Castracane], the most characteristic species found on the surface.

The Chætocerotidæ and Rhizosoleniæ are abundantly represented in the surface waters, but they are only represented by the terminal calyptræ of the latter in the bottom ooze. Most of the delicately curved, though often large, forms, of *Corethron*, and the singular cylindrical *Dactyliosolen*, have only been found in surface gatherings, whilst the remarkable *Trachysphenia australis*, Petit, var. *antarctica* (Schwarz) [=*Fragilaria antarctica*, Castracane], which abounds in the ooze, is much less common in the surface gatherings. Frustules of *Coscinodisci* and *Actinocycli* are also much less numerous at the surface than upon the bottom, but no species which is present in the superficial waters is absent from the ooze.

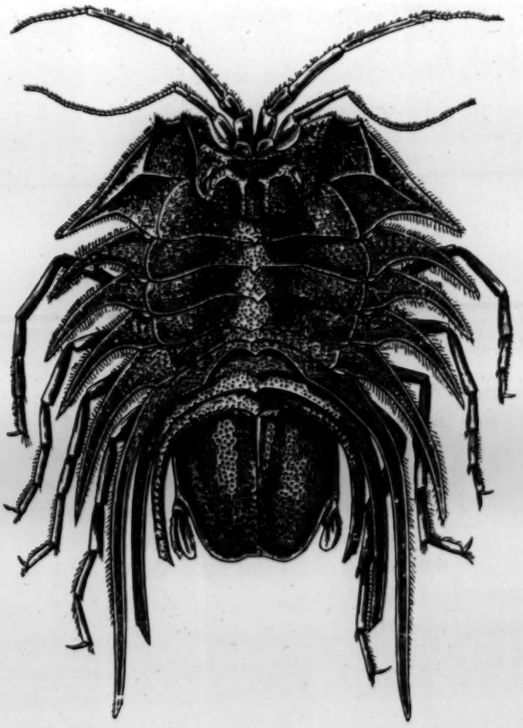
The contents of the alimentary canals of several of the Echinoderms and Annelids were examined with the view of ascertaining whether or not a predilection was exhibited by the animals for any particular species of Diatoms ; it was found, however, that they made use of the ooze as a whole, in all probability taking in the immediate surface layer containing specimens recently fallen from the surface, which, doubtless, still contained some organic matter. The tubes of the Annelids, and the test of the Foraminifera *Reophax nodulosa*, contained many of the large *Coscinodisci* which would appear to have been to a greater extent selected than the others in the deposit.

[1] *Bihang til K. Svensk. Vetensk. Akad. Handl.*, Bd. i., No. 13, Stockholm 1873.

The form, which Count Castracane has indicated as "*Fragilaria?* an *Terebraria?* sp.,"[1] may be regarded as the southern representative of *Fragilaria oceanica*, Cleve, from the Arctic Ocean, with which it shows in the general arrangement and character of the frustules a considerable amount of agreement. Among the Diatoms observed at this Station, the following have been also recorded in the Arctic zone, a few of the species being almost cosmopolitan :—

Navicula aspera, Ehrenberg.
Triceratium arcticum, Brightwell.
Rhizosolenia setigera, Brightwell.
„ *styliformis*, Brightwell.
Chætoceros decipiens, Cleve.
„ *atlanticum*, Cleve.
Coscinodiscus decrescens, var. *polaris*, Grunow.
„ „ var. *repleta*, Grunow.
Coscinodiscus subtilis, Ehrenberg, var. *glacialis*, Grunow.
„ *oculus-iridis*, Ehrenberg.
„ *centralis*, Ehrenberg.
„ *normanni*, Gregory.
„ *kutzingii*, A. Schmidt.
„ *excentricus*, Ehrenberg.
„ *lineatus*, Ehrenberg.

[1] Bot. Chall. Exp., part iv. p. 47, pl. xxv. fig. 1.



Serolis bromleyana, Willemoes-Suhm. A southern deep-sea form.

LIST X.

Surface Organisms observed during the Cruise of the Challenger in the Kerguelen Region.

The following 47 species of Metazoa are recorded in the Challenger Reports from the surface in the Southern Indian Ocean, south of lat. 40° S.:—

Annelida:

Alciopa antarctica, M'Intosh.
Tomopteris carpenteri, Quatrefages.

Ostracoda:

Halocypris atlantica, Lubbock.
„ *brevirostris*, Dana.

Copepoda:

Ætidius armatus, Brady.
Calanus propinquus, Brady.
Candace truncata, Dana.
Drepanopus pectinatus, Brady.
Eucalanus attenuatus, Dana.
Euchæta prestandreæ, Philippi.
Heterochæta spinifrons, Claus.
Leuckartia flavicornis, Claus.
Machairopus idyoides, Brady.
Pleuromma abdominale (Lubbock).
Pseudothalestris imbricata, Brady.
Rhincalanus gigas, Brady.
Saphirinella stylifera (Lubbock).
Scolecithrix minor, Brady.
Zaus spinatus, Goodsir.

Amphipoda:

Atyloides australis (Miers).
Euthemisto gaudichaudii (Guérin).
„ *thomsoni*, Stebbing.
Halimedon schneideri, Stebbing.
Hyperiella dilatata, Stebbing.

Primno antarctica, Stebbing.
„ *menevillei*, Stebbing.
Vibilia antarctica, Stebbing.
Zaramilla kergueleni, Stebbing.

SCHIZOPODA :

Euphausia antarctica, Sars.
„ *murrayi*, Sars.
„ *superba*, Dana.
Thysanoëssa macrura, Sars.

MACRURA :

Caricyphus angulatus, Spence Bate.

LAMELLIBRANCHIATA :

Modiolarca trapezina (Lamarck).

PTEROPODA :

Clio australis (d'Orbigny).
„ *sulcata* (Pfeffer).
Limacina antarctica, Woodward.
„ *australis* (Eydoux and Souleyet).
Spongiobranchæa australis (d'Orbigny).

CEPHALOPODA :

Taonius suhmi (Lankester).

TUNICATA :

Appendicularia sp. (?).
Salpa africana-maxima, Forskål.
„ *cylindrica*, Cuvier.
„ *runcinata-fusiformis*, Chamisso-Cuvier.
Pyrosoma giganteum, Lesueur [trawl, surface ?].

FISHES :

Prymnothonus sp. (?), young.
Sternoptyx diaphana (Herm.) [trawl, surface ?].

The following notes from the manuscript journals of the naturalists bearing on the surface organisms observed during this part of the cruise may be of interest :—

Lat. 45° 57′ S., surface and down to 100 fathoms :—Many Foraminifera of small size with long flexible spines, compound Radiolaria, Ctenophoræ, great numbers of *Sagitta* of

large size, some over two inches in length, *Tomopteris*, Cytherid, Copepods, many small specimens of *Euphausia*, Pteropods (*Limacina*?), and *Cranchia*, a few specimens of which were taken in every haul.

On the night of December 27, 1873, off Prince Edward Island, the tow-net procured many *Salpæ*, larvæ of *Euphausia*, Copepods, several specimens of *Lepas* on a piece of pumice, many specimens of *Hyperia* and *Gammarus*, probably commensalistic and feeding on the *Salpæ*.

In lat. 46° 46′ S., the tow-net was sent down to 80 fathoms, and brought up *Globigerina*, very much smaller than in the Atlantic, compound Radiolaria, many *Sagittæ*, small Copepods, a large species of *Hyperia*, Pteropods, and *Cranchia*.

In lat. 46° 45′ S. the water was quite red-coloured, due to innumerable red Copepods, which were captured in so thick a mass that it was impossible to see the other animals; *Sagitta*, *Hyperia*, and other organisms were, however, present. The red colour of the water, mentioned in the Indian Ocean Directory as occurring among the islands in these latitudes, is probably due to these small Copepods.

Off the Crozet Islands, January 3, 1874, a tow-net was sent down on the dredge rope, and another was towed behind the ship at a depth of about 80 fathoms, and yielded many Diatoms and small *Globigerinæ*, *Sagitta*, *Halocypris*, Copepods, *Hyperia*, Pteropods and Pteropod larvæ, and *Salpæ*.

Off Kerguelen, January 9 to 29, 1874, there were observed Medusæ (*Oceania*), small Planarians, small Tomopterid, *Peltidium*, Calanids and other Copepods, *Gammarus* and another Amphipod, small Isopod, Zoëæ (probably of the Brachyurous crab inhabiting the pools) very small and having just left the eggs. On the floating masses of *Macrocystis* were found Hydroids, Holothurians, small bivalve shells, *Patella*, and Polyzoa. Occasionally the tow-net was completely filled with various species of Diatoms, at other times with Amphipods (*Hyperia*) and numerous Copepods; Pteropods (*Limacina*) were also at times very abundant.

In lat. 52° 4′ S., the tow-nets procured Ctenophoræ, *Sagitta*, young Aphroditaceans, Copepods, *Hyperia*, and *Euphausia*. At times the surface-net was full of living Diatoms, in masses forming a yellowish slime, among which could be distinguished small *Globigerinæ* and Radiolarians. When dragged at a depth of 100 fathoms, the tow-nets produced similar results.

In lat. 60° 52′ S., the tow-nets procured Diatomaceæ, small *Globigerinæ*, Radiolaria (including very fine specimens of *Aulosphæra elegantissima*, Haeckel), Ctenophoræ, Medusæ, *Diphyes*, larvæ of *Chirodota* (?), *Alciopa*, *Tomopteris*, *Sagitta*, Copepods (Calanids), *Hyperia*, *Primno*, Pteropods, and *Appendicularia*.

In lat. 65° 42′ S. were observed *Globigerina*, Radiolaria, *Diphyes*, *Sagitta*, *Alciopa*, Annelid larvæ, *Cypridina*, *Primno*, *Clio*, shell-less Pteropod, and the remains of a large Cephalopod.

During the afternoon of February 17th, 1874, in lat. 65° 5′ S., the sea was of a greenish colour, and the water was found to be filled with many little spherical transparent

masses, which were identical with those Mr MURRAY had observed in the Arctic Ocean. These minute Algæ can be seen in the water with the naked eye, when the vessel is held towards the light; they have the surface covered with little dots of a greenish or yellowish tinge, which, when examined under high powers, were seen to be arranged in groups of four.[1] A few hours later the sea was blue, and these Algæ could not be observed in the water.

In lat. 64° 37′ S., the following surface organisms were collected by Mr MURRAY in a boat, *Euphausia superba* being especially abundant (the supplementary eyes of which were in the evening observed to be phosphorescent):—Diatoms, *Globigerina*, Radiolaria, *Diphyes*, larvæ of *Chirodota* (?) with twelve divided wheels, *Sagitta*, *Cypridina*, and *Euphausia superba*.

In lat. 62° 26′ S. there were observed a few larvæ of *Chirodota* (?), small specimens of *Alciopa* and *Tomopteris*, a very large specimen of *Sagitta* from the trawl, a few Cypridinidæ, Calanids abundant, *Hyperia*, *Primno*. WILLEMOES-SUHM writes:—"The *Euphausiæ*, very common on the surface near the ice, were scarcer in clear water, where the Copepod genera *Calanus* and *Eucalanus* were the most abundant animals."

In lat. 53° 55′ S., among the masses of Diatoms only comparatively few animals were observed, viz., Cypridinidæ, Copepods, *Hyperia*, *Primno*, and a few small shells of *Limacina*.

In lat. 50° 1′ S. were observed a very few Diatoms, *Globigerina*, *Orbulina*, Medusæ, a fine Nemertean [*Pelagonemertes*], which, though taken in the trawl, is evidently a pelagic animal, but probably lives in moderately deep water, *Sagitta*, *Cypridina*, great quantities of the Antarctic Copepods, large *Hyperia*, *Primno*, *Phronima*, and small shells of *Limacina*. WILLEMOES-SUHM writes:—"Some of the surface animals taken to-day indicate that we have entered the warm Indian current, *e.g.*, a *Phronima*, and a large transparent Nemertean, with Dendrocœlous characters, which was two inches in length and showed well the intestine, nervous system, and ovary."

In lat. 47° 25′ S., the tow-nets procured compound Radiolaria, Foraminifera, *Diphyes*, Physophorid, *Apolemia* (?), *Sagitta*, *Cypridina*, Nauplii of a Cirriped (*Archizoëa gigas*, Dohrn), *Hyperia*, *Phronima* with house and young, *Primno*, *Euphausia*, *Sergestes*, Zoëæ, *Atlanta*, and *Appendicularia*.

WILLEMOES-SUHM writes:—"The warm-water animals are in greater number on the surface; there were five specimens of *Pyrosoma*, nearly every one of which had eggs but no embryos. There was a Nauplius, with a carapace like the cap of a Madeira peasant, with many spines, 3 mm. in length; it belongs to *Euphausia*, of which METSCHNIKOFF has figured a similar larva (*Zeitschr. f. wiss. Zool.*, Bd. xxi. p. 396, pl. xxxiv., 1871), but not with such a striking form. There were many adult *Euphausiæ* on the surface. *Phronima* was taken with its house; CLAUS has shown that the house is a young *Pyrosoma* in which *Phronima* establishes itself in order to feed on the Tunicata. He has found all

[1] This Alga has since been described by G. POUCHET as *Tetraspora poucheti*, Hariot (*Comptes rendus des séances de la Societé de Biologie*, 1892).

stages, from the *Pyrosoma* just recently attacked by the Amphipod to those soft remains in which it has been taken by us. Preparations made by us show that the tissues of these houses have the same histological structure as Pyrosomata when treated in the same manner. *Sergestes,* which we have not taken since leaving the Cape, is present at the surface. A little Amphipod, always taken on the surface during our Antarctic cruise, I find now to be *Primno macropa*, which was discovered by GUÉRIN-MÉNÉVLILE near Chili, and which appears to be circumpolar. There were two beautifully transparent Cephalopoda apparently belonging to the genus *Loligopsis.*"

MOSELEY writes :—" The surface fauna is changing ; on the night of the 9th March the sea was full of *Pyrosomæ,* and the wake of the ship was lighted up with them. Moreover this morning several pieces of *Durvillea* were met with, and one piece covered with barnacles caught on the log ; hitherto the sea has been remarkably free from floating weed. This *Durvillea* probably comes from St Paul's and Amsterdam Islands, since these islands lie in the direct course of the South Indian connecting current which, sweeping almost directly eastwards, joins the South Australian current. On the night of the 10th March *Pyrosoma* was again abundant. On the evening of the 11th March there were no *Pyrosomæ* at the surface, but a slight scintillating phosphorescence from the Copepods, and I saw a piece of *Durvillea* float past. *Phronima*, while in its house with its young, moves the whole about by protruding its tail from the end and working it."

Mermaids and Tow-nets.

Recapitulation.

We may now recapitulate the main points of this paper as given in the preceding pages.

The Challenger trawlings and dredgings at eight deep-water Stations in the Kerguelen Region, in depths greater than 1260 fathoms, resulted in the capture of—

272 species of Metazoa, belonging to 186 genera; there are
255 distinct fully-described species, of which
164 species are known only from these dredgings, and
91 species extend into other regions of the ocean, viz.:
38 species are known only from other regions south of the southern tropic,
24 species are known from regions both south and north of (but not within) the tropics,
17 species are known from regions both south of, within, and north of the tropics, and
12 species are known from regions both south of and within (but not north of) the tropics.

164 species confined to this region, added to
51 species which extend into other regions, make a total of
215 exclusively deep-sea species unknown in depths less than 1000 fathoms.
38 species occur both above and below the 1000 fathoms line, of which
19 species extend into shallow water under 150 fathoms (1 from the shore).

Of the 186 genera represented,
30 genera are known only from these dredgings, and other
10 genera are known only from other regions south of the southern tropic, 2 of which extend into shallower water under 1000 fathoms.

The Challenger trawlings and dredgings at the remaining twenty-nine deep-water Stations in the Southern Hemisphere, south of the tropic of Capricorn, in depths greater than 1000 fathoms, resulted in the capture of (avoiding the repetition of those species occurring also in the Kerguelen Region)—

253 species of Metazoa, belonging to 182 genera; there are
233 distinct fully-described species, of which
165 species are known only from regions south of the tropics, and
68 species extend into other regions of the ocean, viz.:
25 species are known from regions within (but not north of) the tropics,
24 species are known from regions both within and north of the tropics, and
19 species are known from regions north of (but not within) the tropics.

149 species confined to regions south of the tropics, added to
31 species which extend into other regions, make a total of
180 exclusively deep-sea species unknown in depths less than 1000 fathoms;
53 species occur both above and below the 1000 fathoms line, of which
20 species extend into shallow water under 150 fathoms (3 from the shore).

Of the 182 genera represented,
19 genera are known only from these dredgings, while another genus known only from regions south of the tropics extends into shallower water under 1000 fathoms.

Combining the results of the Challenger trawlings and dredgings at these thirty-seven deep-water Stations in the Southern Hemisphere, south of the southern tropic, in depths greater than 1000 fathoms, there were captured—

523 species of Metazoa, belonging to 312 genera.
336 species are known only from these deep-water dredgings, and
149 species extend into other regions of the ocean, viz.:
43 species are known from regions north of (but not within) the tropics,
41 species are known from regions both within and north of the tropics,
37 species are known from regions within (but not north of) the tropics, and
28 species are known from shallower water south of the tropics.

There are
390 exclusively deep-sea species unknown in depths less than 1000 fathoms;
93 species occur both above and below the 1000 fathoms line, of which
39 species extend into shallow water under 150 fathoms (4 from the shore).

Of the 312 genera represented,
57 genera are known only from these dredgings, and other
3 genera are known only from regions south of the tropics, but extend into shallower water under 1000 fathoms.

At three dredgings in moderate depths (210 to 550 fathoms) in the Kerguelen Region, the Challenger procured—

68 species of Metazoa, belonging to 61 genera; there are
66 distinct fully-described species, of which
30 species are known only from these dredgings, and
36 species extend into other regions of the ocean, viz.:

21 species are known only from other regions south of the tropics,
7 species are known from regions both south of and within (but not north of) the tropics,
6 species are known from regions both south and north of (but not within) the tropics, and
2 species are known from regions both south of, within, and north of the tropics.

30 species confined to this region, added to
13 species which extend into other regions, make a total of
43 species known only from depths over 150 fathoms (of which 5 species reach deep-water over 1000 fathoms); the other
23 species extend into shallow water under 150 fathoms (of which 3 species are known at the same time from deep-water over 1000 fathoms).

Of the 61 genera represented,

4 genera are known only from these dredgings, and other
2 genera are known only from other regions south of the tropics.

In the shallow waters of the Kerguelen Region, in depths less than 150 fathoms, the Challenger procured—

533 species of Metazoa, belonging to 325 genera; there are
495 distinct fully-described species, of which
326 species are known only from this region, and
169 species extend into other regions of the ocean, viz.:
101 species are known only from other regions south of the tropics,
32 species are known from regions both south and north of (but not within) the tropics,
20 species are known from regions both south of and within (but not north of) the tropics, and
16 species are known from regions both south of, within, and north of the tropics.

326 species confined to this region, added to
92 species which extend into other regions, make a total of
418 species known only from shallow water under 150 fathoms; the other
77 species occur both above and below the 150 fathoms line, of which
28 species extend into deep water over 1000 fathoms;
18 species have been recorded as occurring in the fossil condition.

Of the 325 genera represented,

25 genera are known only from this region, and other
2 genera are known only from other regions south of the tropics.

Over 100 additional species from sources other than the Challenger expedition are enumerated from the Kerguelen Region, but some of them require verification.

There are 90 identical species of Metazoa referred to in the paper as occurring in the extra-tropical regions of the northern and southern hemispheres unrecorded from the intervening tropical zone, and over 50 cases of closely-allied species occurring in the extra-tropical regions of the northern and southern hemispheres separated by the intervening tropics.

In the deposits collected by the Challenger at six deep-water stations and three shallow-water localities in the Kerguelen Region,

220 species of Foraminifera were observed ; there are
206 distinct fully-described species, of which
179 species are known from regions both south of, within, and north of the tropics,
16 species are known from regions both south and north of (but not within) the tropics,
7 species are known from regions both south of and within (but not north of) the tropics, and
4 species are known only from regions south of the tropics.

The wide geographical distribution of these Protozoa is thus in marked contrast to that of the Metazoa previously considered, and the majority have also a great range in depth, for

178 species occur both above and below the 1000 fathoms line, while
14 species occur only in deep water over 1000 fathoms, and
14 species occur only in depths less than 1000 fathoms, of which 6 species occur only in shallow water under 150 fathoms.

In the deposit collected by the Challenger at Station 157, 1950 fathoms, in the deep-water area of the Kerguelen Region,

81 species of Radiolaria were observed, of which
57 species are recorded only from this place, the other
24 species extending into other regions of the ocean, viz. :
22 species are known from other regions both south of and within the tropics,
1 species occurs in other regions only south of the tropics, and
1 species occurs in other regions only north of the tropics.

In the surface gatherings from the same Station in the deep-water area of the Kerguelen Region,

24 species of Radiolaria were observed (of which 12 species occur also in the deposit at the same place),

15 species are recorded only from this place, and

9 species extend into other regions of the ocean, viz. :

6 species are known from regions within (but not north of) the tropics,

2 species are known from regions both within and north of the tropics, and

1 species occurs in other regions only north of the tropics.

In the deposits collected by the Challenger at three shallow-water localities and one deep-water Station in the Kerguelen Region,

187 species of Diatoms were observed (of which 25 species occur both in the deep-water and shallow-water deposits).

In the surface gatherings from Station 157 in the deep-water area of the Kerguelen Region,

51 species of Diatoms were observed (of which 26 species occur also in the deposits of the same region);

15 species of Diatoms from these Antarctic localities are known also from Arctic regions.

In the surface gatherings from the Kerguelen Region of the Southern Indian Ocean, south of latitude 40° S.,

47 species of Metazoa are recorded, along with particulars and notes on other pelagic organisms observed in this portion of the cruise of the Challenger.

Concluding Remarks.

The principal object in view in this paper has been to exhibit the present state of knowledge concerning the deep-water and shallow-water marine faunas of the Kerguelen Region of the Great Southern Ocean, and to compare these faunas with the deep-water and shallow-water faunas in other regions of the ocean. In consequence of the researches of the Challenger Expedition in 1873 and 1874, our knowledge of the faunal conditions of the Kerguelen Region is more complete than that of any other area of the Great Southern and Antarctic Oceans. In view of the possible more thorough exploration of the south polar regions in the near future, it has seemed desirable to summarise our knowledge of the marine organisms of the Kerguelen area, for the use of those who may be engaged in Antarctic exploration, and to point out directions in which future investigations might likely yield some interesting and important results.

In the concluding volume of the Challenger Report, I have pointed out that an analysis of the results obtained by the Challenger's trawlings and dredgings in different parts of the world indicated certain general conclusions with reference to the distribution of organisms over the floor of the ocean. It appears to be established by these investigations that life is everywhere present on the sea-bed in all depths and at all distances from the shore. The number of species in great depths far removed from land is very small when compared with the number of species present in lesser depths near to the shores of continents; the number of species gradually increases towards the shallow water of the continents, the greatest number being found in the whole area less than 50 fathoms surrounding the dry land. The proportion of species to genera is, on the whole, larger in shallow than in deep water, the Challenger results giving a gradually decreasing ratio from shallow water down to the greatest depths, as follows :—

Over 2500	fathoms,	ratio of	species to genera	= 1·17 to 1
2000–2500	,,	,,	,,	1·36 ,,
1500–2000	,,	,,	,,	1·45 ,,
1000–1500	,,	,,	,,	1·50 ,,
500–1000	,,	,,	,,	1·67 ,,
100- 500	,,	,,	,,	2·37 ,,
Under 100	,,	,,	,,	2·93 ,,

The Challenger researches did not indicate the existence of large numbers of individuals belonging to any one species in deep water beyond 1000 fathoms. In lesser depths, however, the number of individuals belonging to a single species was sometimes very large; and just below the 100 fathoms line, where on open coasts fine detrital matters finally commence to settle on the bottom, enormous numbers of individuals belonging to one species are present in, or on the surface of, the mud. A comparison of the species captured in deep water in two widely separated areas under apparently similar conditions did not show many species in common, and on the whole there was little evidence

to show that deep-sea species had a world-wide distribution, as usually supposed. While some deep-sea species present archaic characters, and others recall the fossils of the chalk period, still deep-sea species do not represent such an old fauna as many shore and fresh-water forms living at the present day, such as *Ceratodus*, *Protopterus*, *Amphioxus*, *Trigonia*, *Lingula*, and *Heliopora*. There appears to be little evidence from the Challenger's researches to show that the deep sea has been peopled since the earliest geological times; it is more probable that migration took place from the mud-line into the deep sea at a not very remote geological period. The recent oceanographical researches show that both in deep and shallow water there are large numbers of identical and closely-allied species in the extra-tropical regions of the Northern and Southern Hemispheres which, so far as at present known, are not represented within the intervening tropics, even though in deep water the climatic conditions as regards temperature are the same. It will now be interesting to inquire how far these general conclusions are supported by the foregoing analysis of the results obtained within the Kerguelen Region of the Great Southern Ocean.

The Challenger in the Kerguelen Region made seven hauls with the trawl and one with the dredge in depths exceeding 1260 fathoms. This was probably the most productive series of hauls obtained in deep water in any one region of the ocean during the whole cruise of the Challenger. In 1375 fathoms, exclusive of Protozoa, over 200 specimens of fishes and invertebrates were obtained belonging to 78 species; in 1600 fathoms about the same number of specimens were obtained belonging to 89 species; in 1950 fathoms over 150 specimens were procured belonging to 79 species; the total number of species in the three hauls being 199. The number of species procured in these three hauls with a small twelve or sixteen feet beam trawl is certainly very remarkable when we remember that the depth is about two English miles.[1]

The total number of species of Metazoa obtained at the eight deep-water stations of the Kerguelen Region in depths exceeding 1260 fathoms amounted in all to 272 species. The total number procured in the other twenty-nine stations in the Southern Hemisphere south of the tropic of Capricorn in depths over 1000 fathoms was 301 species, the average per haul in this last case being only 10·4 species, while in the first case the average is 34·0 species per haul. The twenty-nine stations are on the whole situated about seventeen

[1] Since the above was written a list of the species procured in three hauls with a trawl in shallow water (6 to 21 fathoms), off the west coast of England, has been published with the view of showing the large number of species that may be captured in single hauls from the shallower zones of depth (Third Report of British Association Committee on the *Marine Zoology, Botany, and Geology of the Irish Sea*, Ipswich, 1895). The total number of species procured in these three shallow-water hauls was 189, therefore less by 10 species than were procured in the three deep-sea hauls above noted. The most marked difference in the character of the species in these series of deep-water and shallow-water hauls is the predominence of Echinodermata in the deep sea and of the Mollusca in shallow water:—54 species of Echinodermata occurring in the deep hauls, while only 13 species are present in the shallow ones; and 40 species of Mollusca occurring in the shallow hauls, while only 26 species are present in the deep ones. This comparison has been introduced with the view of calling attention to the large number of species in these deep hauls, and not with the purpose of showing that in the deep sea species are more abundant than in shallow and shore regions of the ocean. Though, as already stated, it is recognised that the total number of species present in the whole area of depths less than 50 fathoms all over the world is greater than in deeper water, still we have good reason for believing that in high northern and high southern latitudes the reverse holds good for depths less than 25 fathoms, and that there may be a larger total number of species in deep water than quite close to the land.

degrees further to the north than the eight stations making up the Kerguelen group of stations, and this may have a bearing on the different results in the two groups of stations. The more productive hauls in the deep water of the Kerguelen Region may perhaps be purely accidental, but a more likely explanation is to be found in the physical conditions of the region towards the Antarctic, as suggested in the first paragraphs of this paper.

Of the 272 species of Metazoa captured in the deep-water stations of the Kerguelen Region, it is to be observed that not one species is common to all the eight stations nor even to any seven of the stations; one species occurred at six stations, one at five stations, 2 species each at four stations, 13 species each at three stations, and 40 species each at two stations. In the two deep-sea stations nearest to each other—separated by a distance of 122 miles—there were only 22 species in common out of a total of 145 species of Metazoa. This does not seem to indicate any very wide distribution of deep-sea species within the Kerguelen Region, not indeed much wider than in the case of the shallow-water species as stated on pages 432–433. Again, of the 272 deep-sea species, 164 species are at present unknown outside of the Kerguelen Region, and only 48 out of the 272 species occur in the twenty-nine deep-sea trawlings and dredgings in the other regions of the Southern Hemisphere south of the tropics. The total number of species of Metazoa taken by the Challenger in depths over 1000 fathoms south of the tropic of Capricorn was 523. Of these, 336 species, or 64 per cent. of the total number present, were taken neither in any of the Challenger's trawlings within the tropics nor to the north of the tropics. We thus see that deep-sea species are not apparently much more widely distributed than shallow-water ones, for, as has been stated on page 434, 61 per cent. of the Kerguelen shallow-water species have not as yet been procured outside that area. It may therefore be expected that further dredgings in the deep sea towards the Antarctic will yield a large number of new species of marine organisms.

The Challenger's trawlings and dredgings around Marion, Kerguelen, and Heard Islands, in depths less than 150 fathoms, yielded in all 533 species. There were about forty hauls with the trawl and dredge, but this large number of hauls yielded only about double the number of genera and species procured in the eight deep-sea hauls in depths greater than 1260 fathoms. In the trawlings between 50 and 150 fathoms the hauls were very much more productive than in depths less than 50 fathoms. In 120 and 105 fathoms off Kerguelen the note books say never before were so many animals procured in the trawl, and in 75 fathoms off Heard Island it is said that the bottom was teeming with animal life. These two stations were situated just about the mud-line off the eastern—that is to say the leeward—coasts of Kerguelen and Heard Islands. Off the western or windward shores the mud-line must be situated at a much greater depth, for a gravelly bottom was found at a depth of 150 fathoms between these islands.

The total number of species collected by the Challenger at Kerguelen in depths less than 50 fathoms appears to be only 130 species; in some cases the hauls were from less to deeper than 50 fathoms, so that the separation at this line is not very distinct, and it is therefore not possible to state the number with great certainty. If now we add to these

130 species, 112 species recorded from other sources from shallow water at Kerguelen, we have a total of 242 species of Metazoa. The remarkable result arrived at is that the eight deep-water hauls in depths of about two English miles have yielded 30 more species than are known from Kerguelen down to the depth of 50 fathoms. The result would have been still more striking had the species recorded from the shore down to 25 fathoms been taken for comparison.

This result agrees with observations in other regions of the Great Southern Ocean where there is a low mean annual temperature. The Challenger's dredgings and trawlings at the Falkland Islands in depths less than 12 fathoms yielded only 85 species, while two hauls in depths of 55 and 70 fathoms between the Falklands and the Strait of Magellan yielded 99 species. The German South Georgia Expedition appear to have collected about 170 species of Metazoa in the shallow waters of that island. Altogether, the marine fauna around the land in high southern latitudes appears to be very poor in species down to a depth of 25 fathoms when compared with the number of species present at the mud-line about 100 fathoms, or even at depths of about two miles.

It is of interest to point out that in the deep-water hauls over 1000 fathoms in the Southern Hemisphere, both in the Kerguelen Region and in the other areas south of the tropic, the ratio of the species to the genera is as 1·46 to 1. The ratio of the species to the genera in the Challenger collections from shallow water under 50 fathoms at Kerguelen is about the same, being as 1·47 to 1. When we take all the species and genera recorded from the Kerguelen Region both by the Challenger and other expeditions and extend the depth to 150 fathoms, the ratio of species to genera is only 1·74 to 1. We have shown that the ratio of species to genera in the whole shallow-water zone in all parts of the world is nearly as 3 to 1. This relation of genera to species may be in part elucidated by a comparison of the shallow-water fauna of the Kerguelen Region with the shallow-water fauna of a region within the tropics.

In the vicinity of Cape York, Australia, the Challenger collected in ten or twelve trawlings and dredgings 554 species of Metazoa in depths less than 12 fathoms. This greatly exceeds the number taken in many more dredgings at Kerguelen in depths less than 25 fathoms, and also exceeds by over 20 species the total number collected at Kerguelen, Marion Island, and Heard Island in depths less than 150 fathoms. The result of numerous other comparisons of a similar kind is to show that everywhere within the tropics the number of Benthos species in shallow water much exceeds the number of Benthos species in the shallow water at Kerguelen or areas similarly situated with respect to temperature.

When we compare the orders of marine animals taken at Cape York in depths less than 12 fathoms with the kinds of shallow-water animals taken in the Kerguelen area down to 150 fathoms, we find that all those animals which secrete large quantities of carbonate of lime greatly predominate in the tropical area, as Corals, Macrura, Brachyura, Anomura, Lamellibranchiata, and Gasteropoda. On the other hand, those kinds of animals with little carbonate of lime predominate at Kerguelen, as Hydroida, Holothurioidea, Annelida, Amphipoda, Isopoda, and Tunicata. If we compare the shallow-water Cape

York fauna with the fauna of the deep water of the Kerguelen Region, we find that the same groups on the whole predominate in the deep sea as predominate in the shallow water of the Kerguelen Region. If we compare the shallow-water fauna of the Kerguelen area with the fauna procured in the tropics between 100 and 500 fathoms, we find that the groups present in this deeper area of the tropics resemble much more the shallow-water Kerguelen fauna than is the case with the shallow-water fauna of the tropics. A very large percentage of the Foraminifera found at the mud-line off Kerguelen in 100 fathoms are found within the tropics and indeed all over the world in the mud at similar or greater depths.

The quantity of carbonate of lime secreted by marine organisms is determined by the temperature of the water in which the animals live, and therefore chiefly by chemical rather than by physiological conditions. When neutral ammonium carbonate is added to sea-water at a temperature of 80° or 85° F., the lime salts present—other than carbonate—are rapidly decomposed and thrown out of solution, giving down at once a precipitate of carbonate of lime with the properties of aragonite. When a similar experiment is carried out at a temperature of 40° or 45° F., the precipitate of carbonate of lime separates out very slowly, and in doing so takes the form of calcite. The secretion of lime salts, such as carbonate and phosphate, is effected by the soluble salts of lime in the sea-water forming insoluble compounds with the effete products (principally ammonium carbonate) set free by the metabolism of the organism. The warm waters of the tropics contain ammoniacal salts in much greater abundance than the cold waters of the polar regions. To this fact may be attributed the coral reefs, large shells, and other massive carbonate of lime structures within the tropics, and the very feeble development of carbonate of lime shells and skeletons in the cold waters of the Antarctic, Arctic, and deep sea. A parallel condition of matters with reference to the secretion of carbonate of lime occurs among pelagic organisms. In the tropics numerous species of Pteropods and other Molluscs with carbonate of lime shells are present in the surface waters of the ocean. These species gradually disappear as the cold waters of the polar regions are approached, and in the Arctic and Antarctic are replaced by naked species and one species of minute thin-shelled *Limacina*. The pelagic Foraminifera are represented in tropical waters by about twenty species—some of them, like *Pulvinulina* and *Sphæroidina*, having very thick shells. In the waters of the northern and southern temperate zones a lesser number of species is present and the shells are not so massive. In the cold waters of the Arctic and Antarctic only two small dwarfed species are present. A similar distribution holds with respect to the unicellular Algæ; the calcareous Coccospheres and Rhabdospheres, while abundant in the warm waters of the tropics, are absent from the surface waters of the polar regions.

It is well known that in Palæozoic and even later geological times massive coral reefs flourished within the Arctic circle, and even in Tertiary times massive shells were formed in both the Arctic and Antarctic areas which could not have been secreted were the waters of the polar regions as cold as they are at the present day. It has sometimes

been argued that in ancient times marine animals might have secreted massive lime structures in cold water, but from the considerations stated above this may be regarded as impossible.

The absence of all the pelagic larvæ of Benthos animals from the tow-net gatherings in the cold Antarctic and Arctic waters is another striking fact, as these are universally present within the tropics. The Benthos animals of the cold waters of the polar regions appear to have in nearly all cases a direct development, and the same appears to be the case with deep-sea animals. When coral reefs flourished within the Arctic circle, we must suppose that there was associated with them a large number of animals with pelagic larvæ, as we find in the coral-reef regions of the present day.

Instances of identical species occurring at Kerguelen and on the coasts of Europe are frequently referred to in the notes to the foregoing lists, and in some cases it has been supposed that these animals may have been carried on ships' bottoms from the one hemisphere to the other, but no such explanation can now be entertained, so numerous are the cases of identical species occurring in the far north and in the far south, and not present in the intermediate torrid zone. From very early times the general similarity between the whales, seals, and birds in the Arctic and Antarctic areas has been the subject of remark, and this was attributed to similarity in the physical conditions in the two polar areas.

The first dredgings and trawlings conducted by the Challenger in comparatively shallow water in the extra-tropical regions of the Southern Hemisphere were those about the Tristan da Cunha group of islands. Concerning these WYVILLE THOMSON wrote at the time : "These shallow-water dredgings around Tristan da Cunha gave a great amount of material, the fauna being very much of the same character as that of somewhat shallower water in the north. The species seem in many cases to be identical, but this will require critical examination to determine." This impression was deepened by further trawlings towards the Antarctic, and has been confirmed by the specialists who have reported on the several groups of marine organisms. In the Summary volumes of the Challenger Report I have given lists of the identical species found in the temperate and cold regions of the two hemispheres, but not recorded from the intervening tropical zone. In the present paper further lists are given of identical and closely-allied species which occur in the Kerguelen Region and other areas of the southern hemisphere, and in the northern hemisphere north of the tropic of Cancer, but not within the tropics. Indeed, the marine fauna of high southern latitudes is more closely related to the marine fauna of high northern latitudes than to any fauna in the intervening regions. This is all the more remarkable when we remember that there is hardly a single species of marine Benthos Metazoa common to the east and west coasts of Africa within the tropics, if we except some brackish water and deep-sea species.

In an interesting paper on Arctic and Antarctic marine floras, GEORGE MURRAY and E. S. BARTON write : "Nothing is more striking in the distribution of seaweeds than the change from our northern *Fucaceæ* to the *Sargassa* and other allied genera

of the tropical belt, and then to other *Fucaceæ* again in the south temperate and Antarctic seas."[1] In the paper they give a list of fifty-four species common to the Northern and Southern Oceans but not occurring within the tropics. It has sometimes been supposed that the shallow-water marine animals may pass by way of the deep sea from high northern to high southern latitudes, but this explanation would in no way apply to sea-weeds which can live only in the shallow-waters of the sea. Mr GEORGE MURRAY informs me that the abundance of calcareous incrustation on marine Algæ follows the same distribution as in the case of the lime-secreting animals, these incrustations being much more abundant within the tropics; he says:—"No *Siphoneæ* with encrustation of calcium carbonate occur in the Arctic or Antarctic Seas, or for the matter of that in the colder temperate seas. The *Corallineæ*, which are massively encrusted and occur in great abundance of individuals in the tropics, exhibit a progressive diminution in both mass and number towards the colder areas of the sea. While several genera found in the tropics and temperate seas are absent from the polar seas, the *Corallineæ* are yet represented by four genera in the Arctic Sea. The ten species of *Lithothamnion* recorded from the Arctic Sea would indicate at first sight a high degree of representation of the most massively encrusted genus. But these ten species are notoriously of insecure foundation, and really only form one species in the opinion of some phycologists. In addition to the four Arctic genera of *Corallineæ* two others are recorded (six in all) from the Antarctic region as delimited in the paper quoted. But this again is accounted for by the line of delimitation being too far north and including an area properly south temperate in character. Most other encrusted *Florideæ* are confined to tropical or warm seas. Taking marine Algæ with calcium carbonate encrustation as a whole, it is undoubtedly the case that they diminish both in numbers of species and individuals, and in massiveness of encrustation towards the polar seas."

Whoever may have read the foot-notes appended to the foregoing lists in this paper must have been struck with the numerous instances in which an author was in doubt as to whether a certain specimen should be described as a new species or referred to a known species. The great geographical distance separating the spots where specimens were collected is sometimes considered a sufficient reason for laying great stress on some slight variation, and creating a new species; this is especially the case with specimens from high northern and high southern latitudes. Again, an author has often had a difficulty in deciding whether to include a species in a known genus or to create a new genus for its reception. The descriptions of the several authors very much impress one with the great want of equivalence in the features of an organism which serve as specific and generic characters in the different groups of invertebrates. But for these considerations the resemblances between the marine faunas of high northern and southern latitudes would be much more evident than appears from the statistics in the foregoing pages with reference to the species which have hitherto been recorded from the two polar areas.

[1] *Phycological Memoirs of the British Museum*, part iii. p. 88, London, 1895.

It may therefore be assumed that the identical species now found living towards both poles, or their immediate ancestors, had a world-wide distribution, which involves a nearly uniform temperature throughout the whole body of ocean waters. From what has been stated with reference to coral reefs, and from what we know of the distribution of plants in the coal period, this appears to have been the actual state of matters during the earlier stages of the earth's history; down to the middle of Mesozoic times the ocean had, probably, an approximately uniform temperature of about 70° F. from pole to pole, being probably not much warmer at the equator than elsewhere. The evidence afforded by the distribution of fossils in the geological strata, proceeding backwards in time from the most recent to those of Palæozoic age, indicates that the tropical zone of temperature slowly widens towards the north and south till in the earlier ages it eventually embraced the whole world.

From the general character of the deep-sea fauna, as well as from its distribution over the floor of the ocean at the present day, it cannot be said that there is any evidence in support of the view that from the Silurian period to the present day there had been, as now, a continuous deep ocean with a bottom temperature oscillating about the freezing point, and that there had always been an abyssal fauna.[1] It is more probable that in early times the ocean had a nearly uniform temperature throughout its whole mass, and that, like the Black Sea at the present day, it was uninhabited much below the mud-line, except perhaps by some species of Bacteria.

We may suppose that if cooling set in at the poles towards the middle or close of Mesozoic times colder water then descended to the greater depths of the ocean, carrying with it a larger supply of oxygen, so that it then became possible for animals to live in the greater depths, and migrations slowly took place into the deep sea. A cooling at the poles such as here indicated would bring about the destruction of many shallow-water organisms, especially of those provided with pelagic larvæ and of those which secreted large quantities of carbonate of lime for their shells and skeletons. Owing to the weeding out of these groups of animals a fauna less rich in genera and species would be left behind; the survivors would be chiefly those with a direct development inhabiting the deeper mud-line. In this way we may account for the relatively few species in the shallow or shore waters of the polar regions when compared with the number present in depths less than 20 fathoms within the tropics, and for the absence of pelagic larvæ of Benthos animals in the cold waters towards the poles. The large number of individuals belonging to many of the polar species compared with what obtains within the tropics, as well as the identity or great resemblance of the species in the two polar areas, may be explained by similar considerations, for in water of a low temperature the metabolism in cold-blooded animals would be much less rapid than in water of a high temperature, and all those changes which result in the evolution of new species would proceed at a much slower rate at the poles than in the tropical belt.

As the process of cooling proceeded and the Antarctic continent became covered

[1] Wyville Thomson, *Zool. Chall. Exp.*, vol. i., Introd. p. 47.

with ice and snow, the glaciers descending from the land would destroy the shore and shallow-water fauna, especially those with pelagic larvæ, while those with a direct development would be able to take refuge in the deeper water; migration from the Antarctic continent towards the equator would thus set in all over the sea-bed in the Great Southern Ocean, and the other physical conditions of the area, such as the mixture of currents of different temperatures and the consequent destruction of pelagic organisms, would combine to furnish this deep-sea fauna with abundance of food and oxygen.[1] In this way we may account for the apparently greater abundance of life in the very deep sea of the Great Southern Ocean and the North Atlantic and the North Pacific than elsewhere.

Some geologists have cited the appearances presented by certain ancient conglomerates as evidence for the existence of glacial periods during Palæozoic times,[2] but this hypothesis seems to be in direct opposition to the testimony furnished by the coral reefs preserved in Palæozoic strata within the Arctic circle—indeed, coral reefs apparently flourished in all Palæozoic seas. The vegetation of the Carboniferous formations likewise indicates a universal tropical climate all over the world both on the land and in the ocean. Palæontological evidence points to the gradual diminution of temperature in the higher latitudes of the globe during the later geological periods. When considering the climates of the past it is not so much an excess of light and heat in ancient times as a nearly uniform distribution of tropical conditions over the whole globe, and a progressive withdrawal of the then universal torrid zone within its existing limits, that require explanation.

In seeking for a solution of the problems connected with the geographical distribution of fossils in the geological strata, as well as of those connected with the distribution of existing species over the face of the earth, it has been almost universally assumed that the astronomical relations of our globe have remained stable. This may well be accepted as true for the period covered by human history, but the variation in these relations assumes a very great importance when dealing with the immense duration of geological history. It seems certain that the Palæozoic trilobite looked out on a very different sun from what we now behold in the heavens. In picturing the successive stages in the evolution of the surface features and biological conditions of our globe it is necessary to take into consideration the contemporary evolution of the other members of the solar system, and especially that of the central luminary—the sun.[3]

The nebular theory of the formation of the solar system is now almost universally accepted. It starts from a plenum filled with absolutely cold matter, the potential energy of which is at a maximum, and with a rotatory motion at least equal to that of the whole

[1] See *ante*, p. 352.

[2] See A. Geikie, *Text-book of Geology*, ed. 3, p. 802, London, 1893 ; A. de Lapparent, *Traité de Géologie*, ed. 3, p. 884, Paris, 1893 ; A. C. Ramsay, *Quart. Journ. Geol. Soc.*, 1855, p. 185 ; M. Neumayr, *Erdgeschichte*, Bd. 2, p. 193, Leipzig and Wien, 1890.

[3] See Eug. Dubois, *The Climates of the Geological Past and their relation to the Evolution of the Sun*, London, 1895.

solar system at present. This cold matter falling together under the influence of mutual gravitation developed such an enormous quantity of heat that even its most refractory constituents were at once dissipated into gas. Lord KELVIN says :—"The vapour or gas thus generated will fly outwards, and after several hundreds or thousands of years of outward and inward oscillatory motion, may settle into an oblate rotating nebula extending its equatorial radius far beyond the orbit of Neptune, and with moment of momentum equal to or exceeding the moment of momentum of the solar system. This is just the beginning postulated by LAPLACE for his nebular theory of the evolution of the solar system, which, founded on the natural history of the stellar universe as observed by the elder HERSCHEL and completed in details by the profound dynamical judgment and imaginative genius of LAPLACE, seems converted by thermodynamics into a necessary truth, if we make no other uncertain assumption than that the materials at present constituting the dead matter of the solar system have existed under the laws of dead matter for a hundred million years. Thus there may in reality be nothing more of mystery or of difficulty in the automatic progress of the solar system from cold matter diffused through space, to its present manifest order and beauty, lighted and warmed by its brilliant sun, than there is in the winding-up of a clock and letting it go till it stops."[1]

The mass of rotating hot gas would at once begin to lose heat by radiation into space ; but this loss of heat would cause contraction, which would generate an amount of energy more than sufficient to account for the loss by radiation. In due time the various planets would (either successively, in order of their distances as held by LAPLACE,[2] or either simultaneously or irregularly as held by KIRKWOOD and NEWCOMB[3]) become separated from the gaseous mass as more or less nebulous annuli. These annuli would ultimately condense into planets, which, on account of their small size, would cool down comparatively rapidly. C. WOLF says :—"La période géologique de la Terre, masse de peu d'importance et par suite rapidement refroidie, a donc pu commencer bien avant la formation du Soleil *actuel*, et lorsque la nébuleuse n'avait peut-être pas encore donné naissance à Vénus ni à Mercure. Les géologues pourront trouver, dans le diamètre considérable de la masse solaire à ces époques, l'explication de l'égalité de climat dont paraît avoir joui la terre jusqu'au commencement de l'époque actuelle."[4]

A sun, the diameter of which was equal to that of the orbit of Venus, that is about 137,400,000 miles, would subtend an arc of over 95° in the heavens, and at the nodes, instead of barely illuminating the poles, the rays would pass over both poles and strike the earth as far as the forty-third parallel. The shortest day would be at the equator, and even there it would be of about 18 hours duration. Under such a sun the poles

[1] Lord KELVIN, *Popular Lectures and Addresses*, ed. 2, vol. i. pp. 421–2, London, 1891.

[2] LAPLACE, *Exposition du Système du Monde*, ed. 6, 1836.

[3] KIRKWOOD, "On Certain Harmonies of the Solar System," *Amer. Journ. Science*, ser. 2. vol. xxxviii. p. 5 ; S. NEWCOMB, *Popular Astronomy*, p. 513.

[4] *Les Hypothèses Cosmogoniques*, p. 32, Paris, 1886 ; see also BLANDET, *Bull. Soc. géol. de France*, sér. 2, t. xxv. p. 777, 1868.

would never be in darkness even at the winter solstice, so that poleward of the parallels of 66° there would be no night whatever at any time of the year.

When the sun was reduced to such a size that its rays just grazed the pole at the winter solstice, the thermal history of the earth would have reached an important stage, for this would mark the close of perpetual sunshine at the poles, provided we do not consider the refraction of the earth's atmosphere. When a ray from the sun's limb is tangential to the pole at the winter solstice, that is when the pole is turned away 23° 28′ from the sun, it follows that the angular distance of the limb from the centre of the sun would also be 23° 28′, and the sun would subtend an angle of 46° 56′ in the heavens, its diameter being therefore 72,818,000 miles. This is nearly equal to the diameter of the orbit of Mercury. The precipitation of water, the formation of the first stratified rocks, and the advent of life on the surface of the earth, may possibly have taken place before or have coincided with this stage of the sun's development, and because of the great size of the sun there would be a universal tropical climate on the earth.

At the present time a very little over 50 per cent. of the earth's surface is under illumination; but with a sun in the heavens having an angular diameter of 46° 56′, 69·9 per cent. of the earth's surface would be illuminated. If we assume that the total amount of radiant energy from such a large sun was the same as from the present sun, the amount of light and heat radiated from a unit surface of such a nebulous sun would be much less than from a unit surface of the present sun. Assuming that the insolation due to any element of area of the sun's disc is proportional to the cosine of its zenith distance, then it may be readily shown that, if the total radiation from the large sun be the same as from the existing one, the insolation at any place due to the whole sun is independent of the sun's apparent magnitude, provided the whole of the sun's disc is visible. When, however, only part of the sun's disc is visible, as at sunrise and sunset, the size of the sun has a marked effect on the distribution of heat, the ultimate result being that, at sunrise and sunset, the earth receives an additional amount of energy entirely on account of the sun's greater magnitude.

At the equator the duration of sunrise and sunset, that is the length of time during which only part of the sun is above the horizon, is short compared with other latitudes; the additional heat received at the equator during one whole day, therefore, on account of the increased magnitude of the sun, would be comparatively small, being indeed an absolute minimum at the equinox when the sun's apparent path in the heavens cuts the horizon at right angles. The nearer to the poles we go, the longer does the sun take to emerge completely above the horizon, and the longer is the period during which the sun is only partly seen; the greater therefore would be the quantity of additional energy received on account of the sun's great size. There might thus have been a large luminary, the rate of insolation of which at any place on the earth's surface was equal to that of the sun at present; but from that sun, on account of its great size, the earth as a whole would receive more energy, distributed in the most advantageous manner possible, viz., a very slight increase at the tropical regions, and

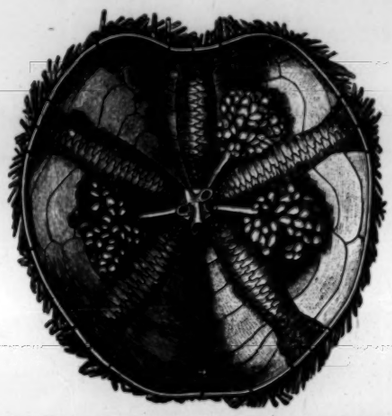
a much greater absolute increase at the poles, the intervening latitudes receiving an amount intermediate between these limits. Such a distribution of energy would tend to that uniformity of climate apparently demanded by palæontological evidence.

A few illustrative figures calculated under the above assumptions may be of interest; in this approximation the effects of solar and terrestrial atmospheres have been neglected. The earth as a whole would receive from the large sun about 7·2 per cent. more energy than at present. At the equinox the equator would receive 2·6 per cent. more energy than it does at present; the polar circle 16·7 per cent. more. At the solstice the equator would receive 3 per cent. more energy than at present; lat. 45° at the summer solstice would receive 4·1 per cent. more. When we consider the insolation at the pole we find that during the whole year the pole would receive between 17 and 18 per cent. more energy from the large sun than from the present small one. As much of this fresh accession of energy would be spread over the period from the autumnal to the vernal equinox, when, at present, the pole receives no heat from the sun, the ultimate effect would be the raising of the temperature during the polar winter.

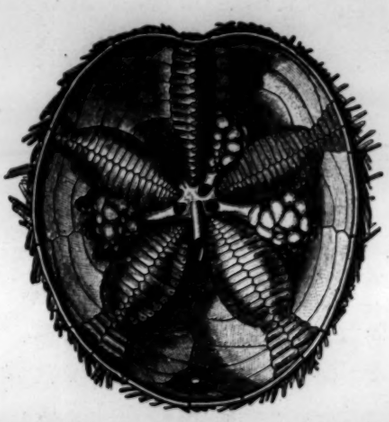
It may be interesting here to state that when the centre of this large nebulous sun rested over either of the tropics, part of the limb would be vertical 23° 28′ polewards from the tropics, that is at the 47th parallel; an equatorial belt 94° wide, having an area of 143,830,200 square miles, or 73·14 per cent. of the earth's surface, would be under the vertical rays of some portion of the sun's surface at least twice in the year. The corresponding region of the earth (having vertical rays) at present has an area of only 40 per cent. of the earth's surface, or about 79,258,000 square miles.

At the summer solstice this large sun would shine over one pole to a distance of 47° on the other side of the pole, that is to say, any place within the 43rd parallel would at the solstice enjoy a 24 hours day. But at the summer solstice a belt 4° in width between the 43rd and the 47th parallels would have the sun in the zenith at noon and at the same time enjoy a 24 hours day. At the summer solstice the total area of the region having a 24 hours day, that is the region polewards from the 43rd parallel, would be 31,269,500 square miles, or 15·9 per cent. of the whole earth's surface, the two polar caps together amounting to 31·8 per cent. At this time the other pole, turned away from the sun, would be undergoing a regular alternation of day and night, the longest night being one of 12 hours, and even that would be only at the pole at the instant of the solstice. The region of a possible 24 hours day at present has an area of about 16,674,200 square miles, or 8·38 per cent. of the earth's surface, only 26 per cent. of what it must have been with a sun of the size above indicated. The complete annihilation of the 24 hours polar night, and the almost perpetual insolation near the pole (only interrupted for a few hours at the winter solstice), would go far to counteract the diminution of energy due to the obliquity of the sun's rays. We must also take into account the fact that the nearer to the pole we go, the higher is the elevation of the sun at midnight, although lower at noon. On the whole, then, we would expect in the tropics warm days and cold nights, and in circumpolar regions cooler days and mild nights, the

diurnal temperature in the two regions tending to balance and approximate closely to the annual mean for the whole earth. In the foregoing we have not taken into consideration the effect of the refraction of the earth's atmosphere on the sun's rays, but it is evident that a very much smaller sun than one subtending an arc of 46° 56′ would produce an equable temperature all over the earth when aided by atmospheric refraction.

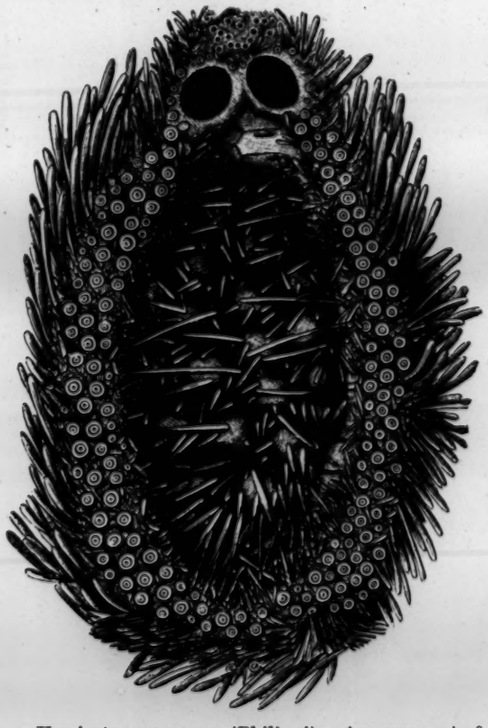


Hemiaster cavernosus (Philippi). Apical portion of test of male seen from within, slightly enlarged.



Hemiaster cavernosus (Philippi). Apical portion of test of female seen from within, slightly enlarged.

Hemiaster cavernosus (Philippi). Accessible Bay, Kerguelen, $\frac{2}{1}$.



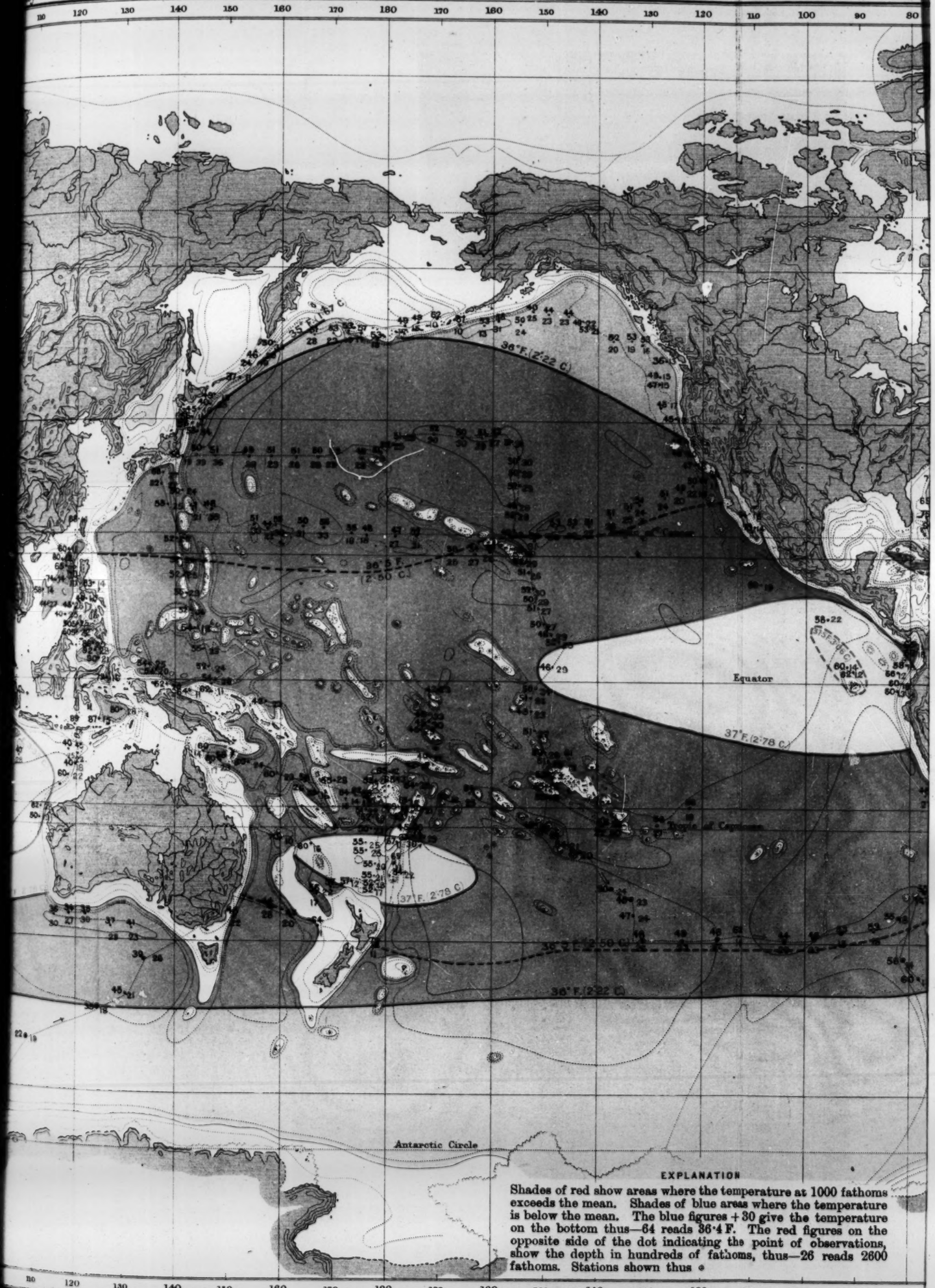
Hemiaster cavernosus (Philippi). Arrangement of eggs in one of the Marsupial recesses, $\frac{4}{1}$.

Explanation of the Map showing the Temperature of the Ocean at 1000 Fathoms and at the Bottom in greater depths.

The accompanying Map has been constructed from materials in Dr Buchan's Challenger Report on Oceanic Circulation, and shows the temperature of the ocean at 1000 fathoms as well as the temperature at the bottom of the ocean in depths greater than 1000 fathoms. The different shades of red and blue within the different isotherms show the temperature in different areas at the uniform level of 1000 fathoms. For the depths below 1000 fathoms the actual observations are given. The *red* figures, on the one side of the *dot* marking the position, give the depth in hundreds of fathoms; thus 28 in *red* figures stands for 2800 fathoms; 11 for 1100 fathoms, etc. The *blue* figures on the other side of the *dot*, plus 30, give the temperature at the depth indicated by the *red* figures; thus 35 in *blue* figures must be read 33°·5 F. and 64 must be read 36°·4 F., etc. Where the temperature is below 30° F. or above 40° F., the temperature has been entered in full to the first decimal place, and in all such cases there are three figures instead of two; for instance, in the Arctic Ocean 292 signifies 29°·2 F., in the Mediterranean 565 signifies 56°·5 F., and in the Sulu Sea 505 signifies 50°·5 F.

At a depth of 1000 fathoms the lowest temperature recorded is 29° F. (−1°·7 C.) in the Arctic Ocean, and the highest in the open ocean is about 41° F. (5° C.) between the Canaries and Madeira, the total range at this depth being about 12° F. (6°·7 C.). It will be noticed that at the depth of 1000 fathoms the North Atlantic is much the warmest ocean, and that the whole of the Atlantic and Indian Oceans is above the average at this depth (36°·5 F.), while the greater part of the Pacific is below this average. The same general features persist to the bottom in each ocean with some slight deviations due to local conditions. The thirty-seven deep-water Challenger stations south of the southern tropic, specially referred to in this paper, are indicated by a circle in black.

MAP SHOWING TEMPERATURE OF THE OCEAN AT 1000 FATHOMS, AND THE TEMPERATURE



E TEMPERATURE ON THE FLOOR OF THE OCEAN AT DEPTHS EXCEEDING 1000 FATHOMS; MEAN TEMPERATURE AT 1000 FAT

100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80

38° F. 3·33 C.

39° F. 3·89 C.

37° F. 2·78 C.

36° F. 2·22 C.

ature at 1000 fathoms
here the temperature
give the temperature
he red figures on the
oint of observations,
thus—26 reads 2600

Track of H.M.S. Challenger shown thus .....

EEDING 1000 FATHOMS; MEAN TEMPERATURE AT 1000 FATHOMS = 36·5 F (2·5 C).

38° F. (3·33 C.)

37° F. (2·78 C.)

36° F. (2·22 C.)

Circle

100 Fathoms
500 "
1000 "
1500 "
2000 "
3000 "
4000 "

FAHR. CENT.

Bartholomew, Edin.

XI.—*On a Case of Colour Blindness.* By Wm. Peddie, D.Sc. (With a Plate.)

Part I.*

(Read 7th January, 18th February, and 3rd June 1895.)

Introduction.

The case under consideration was brought to my notice while I was attempting to arrange a colour match by the well-known disc method. The colour was somewhat like lilac, though rather more red. A number of onlookers—including the gentleman whom I afterwards found to be colour-blind, and whom I shall in this paper denote as Mr A.—pronounced the match fairly satisfactory. Mr A. subsequently remarked to me that he sometimes had a difficulty in distinguishing greens and blues. He said, also, that he had, though much less frequently, a difficulty with reds. This condition is so abnormal that I at once handed him a direct vision spectroscope and asked him to name the colours which he saw in succession from one end of the spectrum to the other. He said that red was the first. "And after the red?" I asked; "green," he said: "and after the green?"; "blue." And when asked what followed the blue, he said that the rest of the spectrum was blue throughout the whole extent. When asked if he saw white light between the red and green colours, he was very undecided, but said that he did not think he would call it white—it might be yellow.

Except for the fact that green and blue were distinguished in the spectrum, the case seemed most like one of blindness to yellow and blue, or "violet-blindness" as it was termed on the original Young-Helmholtz theory.

Next day I showed Mr A. the spectrum formed by a more powerful instrument which gave such dispersion that only about one-quarter of the length of the spectrum could be seen at one time. I asked him to adjust, if he could, the wires to a part which seemed colourless to him. The part which he marked was near the line D on the more refrangible side. I asked him to move the spectrum across the field of vision towards the more refrangible end and name the colours as they passed the centre of the field. He said that there was only one colour, which he called red. The point of strongest red colour he placed near the line C on the less refrangible side, and the spectrum was visible throughout the full normal range towards the red end. In the same way, all the range of the spectrum on the more refrangible side of the neutral point was said to be of one colour, which was called blue. The point of maximum colour was placed between the lines *b* and F—rather nearer the latter than midway between them—and the spectrum was visible to the full normal range

* This part contains results communicated to the Society as follows:—Introduction, 7th January 1895; comparison with the case described by v. Vintschgau and Hering, 18th February 1895; and the rest, 3rd June 1895.

beyond the lines H. I asked Mr A. if he would be as well satisfied in calling that half of the spectrum green, and he said that he would be so.

From the preceding observations, it seemed that the case was one of red-green vision or of blindness to yellow and blue. But there was this striking peculiarity—that Mr A., if he were asked to place the cross wires at the extreme limit of vision at either end of the spectrum, invariably placed them at points corresponding to full normal vision; whereas, in all cases of yellow-blue or "violet" blindness hitherto described—so far as I know—the blue end of the spectrum is considerably shortened, and sometimes the red end is shortened also.

I then showed Mr A. the two complementarily-coloured images which are produced by passing plane polarised light through a plate of quartz and a double-image prism and asked him if he could make the colours alike by rotating the prism. He said that it was impossible for him to do so. The quartz was of such a thickness that the complementary colours were, on the whole, reddish and greenish respectively. I then replaced the quartz by a thinner plate, which gave bluish and yellowish complementary colours, and he said that he could then get equality. The colours which he asserted to be alike were a pale blue and a pale straw colour respectively. This verified the conclusion that the case is one of blindness to yellow and blue.

On the other hand, when the thicker quartz plate was used, I asked Mr A. if he could make *one* of the images colourless? He replied, with some hesitation, that he could; and I was somewhat surprised to find that the colour then was a strong blue-green. This seemed to indicate considerable weakness in the green sensation.

I next showed Mr A. a dark blue, strongly-coloured powder. He said that it was almost black, and he remarked also that a dark blue sky seemed almost black to him. A strongly-coloured yellow powder he pronounced to be almost colourless. Subsequently, I showed him an intimate mixture of these two powders, which was distinctly of a green colour though it was greyish, and he said that it also had no colour.

Colour-Disc Tests.

Colour equations were then obtained in the usual manner by means of the rotation of coloured discs. These are given below. The numbers, as usual, represent the angular measure of the various coloured sectors. The symbols R, Y, G, B, Bk, W, represent respectively red, yellow, green, blue, black, and white. The red was a strong scarlet, containing some yellow; the green was a strong emerald green, containing some yellow; and the blue was Prussian blue, though somewhat dull in tone. The yellow might be called pure.

Limits between which the true match lay were taken. Thus, when a green disc was matched with black and white, the limiting results were

$$\left.\begin{aligned} 360\,G &= 130\,W + 230\,Bk \\ 360\,G &= 110\,W + 250\,Bk \end{aligned}\right\} \quad \ldots\ldots\ I$$

If less white than 110 was taken, the grey was too dark; if more than 130 was taken, the grey was too light. Thus green can be matched with grey. Yet it should be noted that Mr A. always said that he was not satisfied with this match *because the grey disc had a red tinge.* This red tinge was quite obvious to the normal eye and was apparently due to the contrast with the strong green colour. It appeared whether a small green disc was placed on large black and white sectors or small black and white sectors were placed on a large green disc, *i.e.*, whether the green colour was at the centre, or the circumference, of the compound disc. The conclusion is that green, though it does not produce a distinct colour impression, yet can, by contrast, give rise to the complementary colour sensation. This point is considered farther below.

In the same way, with the blue disc, the equations

$$\left.\begin{aligned} 360\ \mathrm{B} &= 132\ \mathrm{W} + 228\ \mathrm{Bk} \\ 360\ \mathrm{B} &= 112\ \mathrm{W} + 248\ \mathrm{Bk} \end{aligned}\right\} \quad \ldots\ldots\ \mathrm{II}$$

were obtained—the match being quite satisfactory.

Again, a mixture of blue and green gave

$$\left.\begin{aligned} 180\ \mathrm{B} + 180\ \mathrm{G} &= 127\ \mathrm{W} + 233\ \mathrm{Bk} \\ 180\ \mathrm{B} + 180\ \mathrm{G} &= 120\ \mathrm{W} + 240\ \mathrm{Bk} \end{aligned}\right\} \quad \ldots\ \mathrm{III}$$

A mixture of red and green gave

$$\left.\begin{aligned} 174\ \mathrm{R} + 186\ \mathrm{G} &= 91\ \mathrm{W} + 269\ \mathrm{Bk} \\ 174\ \mathrm{R} + 186\ \mathrm{G} &= 87\ \mathrm{W} + 273\ \mathrm{Bk} \end{aligned}\right\} \quad \ldots\ \mathrm{IV}$$

a sufficient amount of green being taken to entirely destroy the red. A similar experiment with blue and red gave

$$\left.\begin{aligned} 75\ \mathrm{R} + 285\ \mathrm{B} &= 114\ \mathrm{W} + 246\ \mathrm{Bk} \\ 75\ \mathrm{R} + 285\ \mathrm{B} &= 95\ \mathrm{W} + 265\ \mathrm{Bk} \end{aligned}\right\} \quad \ldots\ \mathrm{V}$$

And, when the blue in this match was replaced by the equivalent amounts of black and white, the match was at once destroyed, the mixture being called red by Mr A., and appearing distinctly red to the normal eye. This proves that the blue, which was matched with grey, possesses, in common with green, though to a less extent, the property of neutralising red.

By repeating observations on these several colour equations, and taking averages for each, a series of self-consistent equations might be found. But it is easy, without the labour involved in that method, to deduce a self-consistent set of equations lying well within the experimental limits.

Thus write

$$\begin{aligned} 360\,B &= (112+p)\,W+(248-p)\,Bk \qquad p \geqslant 20 \\ 360\,G &= (110+q)\,W+(250-q)\,Bk \qquad q \geqslant 20 \\ 180\,B+180\,G &= (120+r)\,W+(240-r)\,Bk \qquad r \geqslant 7 \end{aligned}$$

and we get

$$p+q=18+2r.$$

Say, then, $r=3$, $p=11$, $q=13$, and we get

$$\begin{aligned} 360\,G &= 123\,W+237\,Bk \quad . \quad . \quad . \quad . \quad . \quad (I) \\ 360\,B &= 123\,W+237\,Bk \quad . \quad . \quad . \quad . \quad . \quad (II) \\ 180\,G+180\,B &= 123\,W+237\,Bk \quad . \quad . \quad . \quad . \quad . \quad (III) \end{aligned}$$

Similarly write—

$$\begin{aligned} 174\,R+186\,G &= (87+\alpha)\,W+(273-\alpha)\,Bk, \qquad \alpha \geqslant 4 \\ 75\,R+285\,B &= (95+\beta)\,W+(265-\beta)Bk, \qquad \beta \geqslant 19 \end{aligned}$$

and we get, by elimination of R and the use of equations (I) and (II),

$$\beta-0{\cdot}431\,\alpha=12$$

If, therefore, we assume $\alpha=2$, $\beta=13$, we have

$$\begin{aligned} 174\,R+186\,G &= 89\,W+271\,Bk \quad . \quad . \quad . \quad (IV) \\ 75\,R+285\,B &= 108\,W+252\,Bk \quad . \quad . \quad . \quad (V) \end{aligned}$$

These equations agree (accidentally, to some extent, no doubt) with the following, which was determined by a single observation:

$$180\,R+180\,B=133\,R+60\,W+167\,Bk.$$

Of course the equations (IV) and (V) would give, in conjunction with (I) or (II), an expression for red in terms of a mixture of black and white. They must not be used in that way, because of the fact that green and blue light, though they are equivalent to grey in regard to colour sensation, are not equivalent to a mixture of black and white in regard to complementariness to red.

The yellow disc was also matched with a mixture of black and white, thus

$$\left.\begin{aligned} 360\,Y &= 295\,W+65\,Bk \\ 360\,Y &= 258\,W+102\,Bk \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (VI)$$

Contrast Tests.

A white screen was illuminated by light from two sources—one coloured, the other white—and thus two images of an object, coloured with complementary colours, were thrown side by side on the screen. The first column gives the name of the coloured light and of one shadow; the second gives the colour of the other shadow. The results, as given by Mr A., are put in brackets alongside.

Red (red).	Blue-green (grey).
Reddish-yellow (reddish).	Bluish (grey).
Green (grey).	Bluish-red (reddish).
Blue (grey).	Yellow (no shadow visible).

Again, coloured discs, having the same colours as those which were used in the disc tests, were placed on a white background, and were suddenly withdrawn after they had been gazed at for some time. When a green disc was used, Mr A. saw distinctly the reddish after-image. When red, blue, and yellow discs were used, he saw no after-image.

In this way it is proved that the green colour, though it was grey to him, could yet produce the complementary red colour by contrast.

Spectrum Tests.

Colour Nomenclature.—Mr A. was shown a patch of practically monochromatic spectrum colour and was asked to describe its appearance. The results are given below, the normal terms being in the left-hand column and Mr A.'s in the right-hand column.

Dark red	Dark red.
Bright red	Bright red.
Orange-red	Red.
Reddish-yellow	Warm white.
Slightly reddish-yellow	Less warm white.
Yellow	White.
Very yellow-green	White.
Yellow-green	Very nearly grey (mixed with something).
Green	Very nearly grey (mixed with something).
Bright blue-green	Greyish.
Blue	Grey.
Strong dark blue	Grey (darker than last).
Violet	Dark grey.
Dark violet	Darker grey.
Very dark violet	Still darker grey.
Darkest visible violet	Very dark grey (no red).

Mr A. at first said that he knew the difference between green and blue and that he could distinguish them, but it was easy to prove to him that he could not do so. When asked to name the colour, he was as often wrong as right. So that it is very questionable if the statement " mixed with something " is of much value.

Spectrum Matches.—Two patches of monochromatic light were looked at side by side. While one was always yellow, the colour of the other was varied at pleasure. The intensity of either could be altered until it was equal to that of the other. In this way Mr A. matched with yellow, more or less darkened, all the colours yellow-green, green, blue-green, blue, indigo, and violet, to the extreme end of the spectrum. I then, unknown to Mr A., changed the yellow patch to dark red, and, making it almost invisibly dark, made the other patch violet, and asked him to adjust them to equality. He at once said that it was impossible to do so as the one was red. The same result happened when the dark red patch was made a yellow-red and was darkened. He asserted that he never saw red in spectrum violet.

As in the previous observations, Mr A. said that he was thoroughly satisfied in calling all the first-mentioned colours greys, with the exception of green and blue-green, which he said made a somewhat unsatisfactory match with yellow, though I did not find that the unsatisfactoriness was sufficient to enable him to distinguish green from blue. Nevertheless I believe that it indicates that the green sensation is very nearly appreciated.

Superposition of Spectrum Colours.—The first and second columns contain the names of the superposed colours, and the third column contains the name of the mixture. The names used by Mr A. are in all cases given in brackets.

Red (red).	Green (grey)	Yellow (white).
Red (red).	Blue (grey).	Grey (grey).
Yellow (white).	Dark blue (grey).	Grey (grey).
Yellow-green (grey).	Indigo (grey).	Blue (grey).
Green (grey).	Violet (grey).	Blue (grey).

Comparison with the case described by v. VINTSCHGAU *and* HERING.

The experimental investigation of this case is given very fully by v. VINTSCHGAU in *Pflüger's Arch. f. d. ges. Physiol.*, Bd. 48, s. 43, and Bd. 57, s. 191. HERING'S discussion is given in Bd. 57, s. 308 of that journal. There was great reduction in the intensity of light from the normal value and the spectrum was much shortened at both ends. Roughly speaking, red light began to be visible about half-way between the lines C and D and vanished before D was reached. The spectrum was colourless from the latter point until the yellow-green part was reached. This part was called " yellow." The rest was called " green," up to a point slightly beyond F, then all colour again vanished, and all light disappeared before the line G was reached.

HERING proved that this case was a distinct case of blindness to yellow and blue with a neutral point in the yellow part of the spectrum and another in the blue part. He also proved that, though the light adjacent to this second neutral point was termed colourless, the light on the less refrangible side possessed a green valency, while the light on the more refrangible side possessed a red valency.

In Mr A.'s case, the reduction of intensity, if it occurs at all, is so slight that the spectrum is visible to its full extent. The red part is visible over its whole normal range, and no colour is visible in any other portion.

Conclusion.

Mr A.'s case is, strictly speaking, one of blindness to all colours except red. Yet it is not a case of monochromasy. It seems to be strictly a case of dichromasy, for all the tests show that there is a true neutral point in the yellow part of the spectrum, and that the colourless light of the green and blue parts is complementary to the red. I cannot certainly say as yet that there is no second neutral point in the blue part of the spectrum, but I have not got the slightest evidence of it or of the existence of a red valency in the violet region. Yet Mr A. seems to possess the full normal sensitiveness to red. He can detect the existence of red in white or black apparently quite as soon as an observer who possesses normal vision can. He can distinguish the various shades of red and name them correctly—marone, scarlet, strawberry, &c., and even pink. Of course, in the latter case, he might be deceived by a red mixed with grey instead of blue. Yet, as I have stated, he has never shown any tendency to speak of the violet light of the spectrum as red. Still, the point is not decided, and I intend to investigate it further.

The fact that the violet end of the spectrum is unshortened precludes the case from being described as the "violet-blindness" of the unmodified YOUNG-HELMHOLTZ theory. Yet the neutral point in the yellow is in agreement with that description. In "partial green blindness," on this theory, the spectrum has its full length, and, though a large part of the green portion may be grey, the blue is visible. The immense differences in the appreciation of red and green, laying aside the question of a second neutral point, tell against the application of HERING'S theory. In any case, the modern modification of the YOUNG-HELMHOLTZ theory can apply. I have already given a discussion of the bearings of the case on the theories, but I defer its publication until the experimental investigation is completed.

It is interesting to compare the case with the only genuine case of "violet-blindness" which Captain ABNEY has met (up till 1895). In the latter, the spectrum was shortened at the violet end and there was a neutral point in the yellow part. Only two colours were named—red and *black*. Green was called "bright-black," though it did not satisfactorily match a darkened white patch. Blue was called "dark-black." Suppose

the spectrum to be extended to its normal length, substitute the word "grey" for "black," and we have Mr A.'s case.

I append some illustrations of Mr A.'s colour matches. All matches are placed together in columns—four matches in the left-hand column, four in the central column, and two pairs of matches in the right-hand column. Though he sees no difference in colour between the members of the upper pair in the last column, Mr A. can readily distinguish them, and describes the one with a blue tinge as having a dirty or washed-out appearance.

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COLOUR MATCHES IN A CASE OF DICHROMASY.

John Bartholomew & Co., Edin.r

XII.—*The Development of the Müllerian Duct of Amphibians.*

By Gregg Wilson, M.A., B.Sc. Edin. (With Two Plates.) *Communicated by* Prof. Cossar Ewart, M.D., F.R.S.

(Read 3rd December 1894.)

Last summer I began an investigation of the Müllerian duct of Amphibians at the suggestion of Professor Wiedersheim, to whom I am indebted for most kind advice during the progress of my work, as well as for all the material that I have made use of in the course of it.

I have been able to examine stages in the development of the duct in *Rana esculenta*, *Triton alpestris*, *Salamandra atra* and *S. maculosa*, *Siredon pisciformis* (Axolotl), and *Desmognathus*; but I have paid special attention to *Salamandra atra* and Axolotl, which have not yet been studied in this connection. The Urodeles are easier to work with than the Anura, owing to the comparatively early formation of the *Anlage* of the Müllerian duct; and I have found Axolotl to be particularly instructive, as the pronephros and segmental duct persist during the early stages of the formation of the Müllerian duct.

I propose in this paper to describe what I have observed in various stages of the development of these two forms, and to compare the results thus arrived at with the appearances described in the published works on the subject.

Literature.

At the present time there is commonly said to be a sharp distinction in the modes of development of the Müllerian duct of Anamnia on the one hand, of Amniota on the other. Within the last few years, however, the difference has occasionally been called in question: workers on the Amphibia have declared that they have found the duct originating in the manner supposed to be proper to the Amniota; and quite recently it has been asserted that, alike in Anamnia and Amniota, the duct develops in the mode generally described as characteristic of the former. The original improbability that there should be two fundamentally distinct modes of origin has thus been accentuated: the similarity throughout the Vertebrata is at least so great that in a discussion of the Amphibia the evidence as to other forms cannot be ignored. But though I shall from time to time cite the observations that have been made on other groups, I shall not attempt to review the whole of the extensive literature that deals with the development of the Müllerian duct. I shall merely give such a summary as will show the nature of the evidence concerning the origin of the duct in the Amphibia.

The current controversy, as to whether the Müllerian duct arises independently from the cœlomic epithelium or by the splitting or budding of the segmental duct, dates from the time of publication of SEMPER'S great work, "Das Urogenitalsystem der Plagiostomen" (1875). For fifteen years subsequently each but one of the few workers who studied the development of the duct in Amphibia supported an origin similar to what had been described by SEMPER for Selachians; in 1890 MARSHALL and BLES stated that they had not been able to observe any such splitting of the segmental duct as had been asserted for Rana; and since 1890 three papers have appeared supporting the independent origin of the duct in Gymnophiona, Urodela, and Anura. The literature on the development of the Müllerian duct in Amphibia thus falls into three groups: such as was published before 1875, from 1875 to 1890, and from 1890 onwards.

With the first period I need not concern myself much. MARCUSEN (1851) believed in the *direct conversion* of the segmental duct into the Müllerian duct; LEYDIG and WITTICH, proceeding on a more accurate knowledge of the comparative anatomy of Amphibia, thought that only the anterior part of the segmental duct was employed in the formation of the Müllerian duct. WITTICH founded on his observations on male Urodela and female Anura the opinion: "dass ein und dasselbe fötale Organ hier zu den ausführenden weiblichen, dort zu den ausführenden männlichen Geschlechtsapparaten umgewandelt wird, in beiden Fällen aber auch als harnleitender Apparat fungirt, bei jenen in seiner ganzen Länge, bei diesen nur in seinem hinteren Theile." This view that the segmental duct is divided into a sexual and a urinary channel has often been repeated.

As late as 1875 the opinion advanced by WITTICH and LEYDIG seems to have been unquestioned. In that year GÖTTE, in his "Entwickelungsgeschichte der Unke," simply says, as to the genital ducts, that he holds a repetition of their researches to be unnecessary.

But work on other groups had already prepared the way for a change. In 1867 BORNHAUPT, investigating the fowl, found for the first time the independent formation of the Müllerian duct from a thickening of the epithelium of the mesonephros. In 1870, too, GEGENBAUR had argued for a *splitting* of the segmental duct; but he rested his case entirely on Comparative Anatomy, rather than on direct observation. Finally, in 1875, SEMPER'S work on the urogenital-system of Plagiostomes appeared; and in it he showed that "Bei den Plagiostomen theilt sich der primäre Urnierengang wenigstens im weiblichen Geschlecht vollständig in zwei andre Canäle, deren einer als Müllerscher Gang oder Tube den vorderen Trichter des Urnierengangs sich aneignet, sich aber gleichzeitig gänzlich von der Niere trennt; deren andrer nun Ausführgang der Niere wird und sich abermals in Leydig'schen Gang und eigentlichen Harnleiter spaltet."

SPENGEL (1875), a pupil of SEMPER'S, working in the Zoological Institute at Würzburg, was the first actually to describe a splitting in the segmental duct of Amphibians. At the end of a short "vorläufige Mittheilung" on the "Segmental-organe der

Amphibien," he adds the note : " Anhangsweise sei noch bemerkt, dass sich mir an Tritonlarven ergeben hat, dass auch bei Amphibien die Bildung des Wolff'schen und Müller'schen Ganges durch eine von vorn nach hinten fortschreitende Spaltung des primären Urnierenganges erfolgt, wie es SEMPER für die Haie nachgewiesen hat." But, so far as I have been able to ascertain, SPENGEL never published any details to support this part of his preliminary notice : his later paper, " Das Urogenital-system der Amphibien " (1876), embraces only the anatomical part of his researches. SEMPER, however, gives him as his authority for the statement that in female Amphibia, the splitting of the segmental duct is complete, while in the males it is incomplete ; but, perhaps, this is a mere anatomical observation. And SPENGEL himself, writing on the Cœcilia, says : " Nach den von mir von andern Amphibien vorliegenden Beobachtungen entsteht der Harnleiter in dieser Thierclasse wie bei den Selachiern durch eine von vorn nach hinten fortschreitende Abspaltung an der medialen Seite von dem einfachen Urnierengang."

In 1876 a paper by A. SCHNEIDER appeared, representing a totally different view. The error of WITTICH and LEYDIG, in supposing that the anterior of the segmental duct was simply converted into the Müllerian duct, was shown by the fact that the two ducts run side by side for a considerable period of the larval life of Urodeles. In the case of the frog, the appearance of young cells " um den Wolff'schen Gang " is described : " Während nun die vordere Strecke des Wolff'schen Ganges schwindet, entsteht aus den jungen Zellen der Müller'sche Gang." This work, like SPENGEL'S, was a short one, and without illustrations, but it is interesting as anticipating the conclusions of JUNGERSEN and MACBRIDE.

In 1877 FÜRBRINGER'S splendid account of the " Entwickelung der Amphibienniere " appeared. He adheres to the conclusions of SPENGEL ; but as he gives the process of reasoning by which he was led to do so, it is possible to combat the inference, and I shall, later on, offer another explanation of his facts.* In subsequent writings he renewed his statements as to the splitting of the segmental duct.

The next work of importance was HOFFMAN'S " Entwickelungsgeschichte der Urogenitalorgane bei den Anamnia " (1886). KOLLMANN had in 1882 written on " Verbindungen zwischen Cœlom und Nephridium," but as his paper rather aims at giving an explanation of the work of others than stating new facts, it can hardly be used as evidence for either side of the controversy, though it might be claimed for both. KOLLMANN accepts the view that the Müllerian duct arises from the segmental duct, but insists that it is ultimately a derivative of the cœlomic epithelium.

HOFFMANN'S very elaborate descriptions of the Müllerian duct in the frog and newt are the most exhaustive that we have,—at least, with the exception of JUNGERSEN'S. He, too, adopts the view that there is a splitting of the segmental duct ; but he makes an important modification as to the frog : he says, " Nur *ein kleines Stück* des Müller'schen Ganges entsteht durch Abspaltung von dem ursprünglichen Segmentalgang, *der übrige bei Weitem grössere Theil*, d.i., das ganze Ostium abdominale tubæ so wie der

* See pp. 517-518.

ganze nach hinten bis zur Kloake sich fortsetzende Theil, *legt sich durch Neubildung an.*" He also remarks that before the fission the segmental duct "auf den Namen einer Röhre kaum Anspruch machen kann." The first statement renders his opinion alike difficult to believe and difficult to disprove. The second indicates a possible source of error. I shall deal specially with what HOFFMANN said as to TRITON when I have described my own observations.*

Since HOFFMANN wrote, MARSHALL and BLES have investigated the development of the frog without finding any splitting of the segmental duct; SEMON (1891), after a full examination of Ichthyophis, has written: "Ich betrachte daher als sicher, dass bei Ichthyophis der Müllersche Gang ohne Beziehung zum Vornierengang und zur Vorniere entsteht." MACBRIDE has described the development of the Müllerian duct of Rana as due entirely to cœlomic epithelium; and JUNGERSEN has published an extensive account of the facts in Rana and Triton, and comes to the same conclusion.

Meanwhile, after it seemed proved by the works of WALDEYER, GASSER, BRAUN, RENSON, JANOSIK, MIHALKOVICS, HOFFMAN, WIEDERSHEIM, and others, that the Müllerian duct of *Amniota* was due to a proliferation of cœlomic epithelium, we have this year two publications which aim at showing that this is not so.

M. J. VAN ERP TAALMAN KIP, after studying various of the Insectivora and Rodentia, has come to the conclusion that the two extreme modes of development, as found in Selachians and Reptiles, are connected by others which exhibit partial splitting, partial independent growth. He even holds that within such a group as the Birds, or within a genus, there may be variability and a greater or less adherence to the original mode of development by splitting from the segmental duct. He holds, for instance, that the fowls investigated by BALFOUR and found to exhibit fission of the segmental duct were "more primitive" than those made use of by continental zoologists and which showed an independent origin for the duct.

BURGER writes in a very different strain; but he, too, seeks to reduce to uniformity the diverse modes of development of the Müllerian duct. He has worked on the duck and Tadorna; and having come to conclusions identical with those of BALFOUR and SEDGWICK concerning the fowl, he criticises the investigations of MIHALKOVICS and WIEDERSHEIM on Reptilia; accepts AMANN'S evidence that in the sheep the Wolffian duct takes part in originating the Müllerian duct; and concludes that probably in all the groups of Amniota, as well as in the Anamnia, the Müllerian duct arises by the splitting of the segmental duct.

The literature of the subject is thus in a state of confusion, from which further investigation alone can free it.

The First Anlage of the Duct.

In an embryo (A) of *Salamandra atra*, 11·5 mm. in length, a little anterior to the pronephros, one finds the body-cavity divided into five spaces (fig. 1). Dorsally on

* See p. 518.

each side there is a diverticulum (d^1) which has been cut off by an outgrowth of the radix mesenterii; next come two middle diverticula (d^2) formed by the fusion of the lungs with the lateral walls; and the remainder of the cœlom, ventral to the gut and lungs, forms the fifth division (c).

Where the pronephros begins the cœlom is simple at this stage of development, though at later stages the epithelium on the pronephros is found to be divided by the backward growth of the radix mesenterii and the connection of the lung with the body-wall.

Anterior to the first nephrostome, the pronephros is remote from the median line of the body-cavity, lying as far lateral as possible. Further back, the pronephros is dorsal as well as lateral, and the second nephrostome opens much nearer the middle line than the first.

The glomerulus of the pronephros appears exactly opposite the posterior of the first nephrostome, and extends back through twelve sections, two-thirds of the distance between the two nephrostomes. In several sections towards its posterior end it appears (on both sides) fused with the peritoneal epithelium on the pronephros.

The ordinary epithelium on the pronephros is low, plate-like, and inconspicuous; the nephrostomes, on the other hand, are lined with distinct flagellate cells of cylindric form, which pass into an epithelium whose cells are brick-shaped; while this, in turn, gives place somewhat suddenly to the ordinary peritoneal epithelium. There is thus a *plate of heightened cells round each of the nephrostomes;* and I regard this fact as of considerable interest, inasmuch as in later stages the isolated patches of heightened epithelium unite and give rise to one plate of considerable dimensions, from which, as I shall show, the anterior of the Müllerian duct is formed.

Posterior to the pronephros the segmental duct, after passing nearer to the middle line and turning in a spiral, goes backwards in a straight line to the mesonephros. It is worthy of note that this spiral in the course of the segmental duct occurs just where HOFFMAN has described a splitting of the duct to form Müllerian and Wolffian ducts. The appearance of single sections might well lead to the supposition that there was splitting or budding (figs. 2, 3, and 4), where examination of a series reveals only change of position of the duct.

In another specimen (B) 13 mm. in length, the relations of parts are somewhat different. At the level of the beginning of the pronephros the alimentary canal is now united with the dorsal wall of the cœlom over its whole surface, and the cœlom is divided into three distinct regions by the fusion of the lungs with the lateral walls. Five sections further back (in the sixth section anterior to the first nephrostome), the five-fold division of the body-cavity is met with; and in this specimen is still found at the level of the first nephrostome (fig. 5).

In this case, therefore, the first nephrostome opens not into the simple cœlom, but into a diverticulum of it (d^1 fig. 5) that is inclosed by the secondary attachment of the alimentary canal. The heightened epithelium in the neighbourhood of the first

nephrostome is accordingly very much contracted in breadth; but it extends distinctly for several sections anterior to the opening and for about a score of sections posterior to it. The cells are brick-shaped, and extend so far laterally as to meet the outgrowth of the body-wall that projects to meet the radix mesenterii. The secondary attachment of the alimentary canal ceases behind the sixth section posterior to the first nephrostomial opening; but the lateral outgrowth continues for other fourteen sections (fig. 6).

Four or five sections posterior to the termination of the first patch of thickened epithelium the plate that surrounds the second nephrostome begins. It extends across the pronephros for a few sections, and then becomes much reduced. Yet it can be followed as a narrow thread of cells through the eight sections succeeding the close of the second nephrostome; in the ninth section, which occurs just where the segmental duct makes a spiral turn before running straight backwards, a remarkable thickening occurs, and the epithelium forms a ciliated depression (*p*, fig. 7). I have found no similar appearance in any other specimen.

For five or six sections posterior to the depression the thickening of the epithelium is noticeable, and then ceases. It lies outside the segmental duct.

The segmental duct passing back from the pronephros shows a more prolonged spiral than in "A," with the result that at short intervals appearances such as are indicated in figs. 8–11, and which might in many cases be taken as indicating a budding, are found on different sides of the duct.

The glomerulus begins on one side in the seventh section behind the first nephrostome, and ends just opposite the second nephrostome. It fuses with the peritoneal epithelium of the pronephros a few sections before its posterior end. On the other side the glomerulus begins two sections anterior to the opening of the first nephrostome.

A specimen (C) 20 mm. in length shows in the section that meets the first nephrostome only three divisions of the cœlom. The fusion of the lungs with the lateral walls is in this region complete, so that there is now no middle diverticulum. The attachment of the alimentary canal to the body-wall, on the other hand, is just as in "B," —the diverticulum persists to receive the anterior nephrostome, but it begins only three sections anterior to the opening.

On both sides, the glomerulus begins one or two sections in advance of the first nephrostome. On one side it continues to one, on the other side to the fourth section posterior to the pronephros.

Between the two nephrostomes there is a continuous plate or band of heightened epithelium, which continues for a few sections posterior to the second nephrostome, but without forming a ciliated depression as in "B." It is immediately posterior to the second nephrostome that the lateral connection of the gut with the body-wall ceases, and here the heightened epithelium runs far round the ventral wall.

In specimen "D" (32 mm.) the relations in the anterior region of the cœlom are very similar to those described in "C." Where the funnel of the first nephrostome

lies, the cœlom is very much reduced by the existence of secondary tissue, which surrounds the alimentary canal and envelops the lungs, covering the entire body-wall except a small ventral region.

Opposite the apparently closed funnels of the anterior nephrostomes there are slight diverticula of the cœlom containing the glomeruli; but there are no diverticula dorsal to the lungs. These appear a few sections further back.

On both sides, the anterior nephrostomes, though apparently closed, open backwards into the body-cavity by means of narrow superficial tubes, whose apertures are considerably more posterior than the original funnel.*

Between the new mouth of the first nephrostome and the second nephrostome the usual band of thickened epithelium runs. It covers the entire dorsal face of the diverticulum, but is particularly distinct laterally, *i.e.*, where it meets the attachment of the gut. Where the alimentary canal becomes free from the lateral walls the thickening is found to run far round ventrally. It can be traced into the middle diverticulum as far as the peritoneum has not been encroached on by the secondary attachments, so that it appears that *the heightened epithelium of the pronephros region has simply been divided anteriorly by the backward growth of the attachment of the alimentary canal.* A wedge-shaped region of the epithelial plate has been covered over, and two tapering anterior processes connected by a posterior transverse band persist. The attachment of the gut ceases immediately posterior to the second nephrostome, and the two bands form one broad plate, which, however, soon runs down to a narrow band that passes along the segmental duct towards the posterior end.

My next stage ("E") of *Salamandra atra* is found in a specimen 37 mm. in length. The pronephros has in it undergone extensive degeneration, and there is only an almost median remnant of the posterior part of it. The dorsal diverticula seem practically closed up by the attachment of the gut, and there is no sign of nephrostomes or of the heightened epithelium between them. Beyond the secondary attachment, however, *i.e.*, in the middle diverticulum, a narrow band of thickened epithelium runs back. It passes obliquely round the posterior of the attachment of the gut—behind the remnant of the pronephros—and then back along the segmental duct as a more or less distinct ridge of cells. The segmental duct is in many places quite indistinct.

To illustrate a stage intermediate between "D" and "E" I have figured sections of a *Salamandra maculosa* of 29 mm., showing the cutting off of the dorsal band of thickened epithelium and the connection of the unsuppressed remnant with the narrower and more ventral band that here, as in *Salamandra atra*, runs along the middle diverticulum, and serves as the foundation of the anterior end of the Müllerian duct. In fig. 12 the much reduced band opposite the second nephrostome is shown to be separated from the deep and narrow lateral band by the attachment of the gut. Fig. 13 shows the third section further back, and illustrates how the two bands form one where the secondary attachment ends.

* For further particulars as to the closing of the nephrostomes, *vide* p. 519.

The immediately following stages in the development of the Müllerian duct may better be followed in Axolotl than in Salamandra, to which, however, I shall return later on.

In an Axolotl of 25 mm. (*a*) I find the Müllerian duct in a condition similar to that just described in *Salamandra atra* "D." The anterior nephrostome opens into the usual dorsal diverticulum, along the lateral margin of which there runs a band of thickened epithelium continuous with the heightened columnar epithelium of the two nephrostomes (fig. 14). The connection of the gut and lung with the body-wall ceases on one side slightly anterior, on the other posterior to the second nephrostome, and in each case there is an immediate lateral expansion ; in the posterior region of the pronephros the epithelial plate spreads over the whole surface of the pronephros, and beyond it upon the lateral wall of the body-cavity (fig. 15). On the one side there is no middle diverticulum remaining, and the plate lies entirely posterior to the attachment of the gut and lung; on the other side there is a slight middle diverticulum, and in it a lateral anterior band of thickened epithelium is found. In the latter case, where the lung is fusing with the epithelium, there is a division of the lateral plate ; so that here again, while one process runs in the line between the two nephrostomes, another passes along the ventral diverticulum (fig. 14).

The two segments of the plate unite opposite, or on one side some few sections anterior to the second nephrostome, and on both sides the lateral plate ends opposite or just behind the second nephrostome ; but the brick-shaped epithelium is continued backwards as a thin thread that lies outside the segmental duct.

It is in this region, immediately posterior to the second nephrostome, that the splitting or budding of the segmental duct has been alleged to occur in Amphibians, and I have carefully examined my sections to find if any evidence of such splitting or budding could be discovered. My next stage in the development shows a well-marked *rod* of cells in this neighbourhood as the precursor of the Müllerian duct, and I have had to consider what tissue of the slightly earlier "*a*" stage gives rise to this rod. Here there is only an undifferentiated band of cells ventral to the segmental duct ; it is a direct continuation of the thickened epithelium of the pronephros, and it runs back into a thread of cells that is equally clearly of epithelial origin. In some sections the cells that represent the Anlage of the Müllerian duct are closely applied to the segmental duct, but the segmental duct is well marked and distinct from the Müllerian duct Anlage, both in outline and in its susceptibility to stains ; and there is no differentiation in the cells that lie to the outside of the duct ; there is *one* layer apparent—the epithelium.

A specimen ("B") 27 mm. in length differs essentially from the last described specimen only in the region behind the second nephrostome. The two nephrostomes are still open ; there is the same thickened epithelium ;* but where the lateral band

* See fig. 1 in my Preliminary Note on the Development of the Müllerian Ducts in Axolotl, *Anat. Anzeiger*, ix. Bd., 1894.

runs down to lie opposite the segmental duct there is an important difference. The epithelium shows no longer merely a thickening of two or three cells deep; it is differentiated to form a *rod of cells* (fig. 16). The segmental duct is still intact; its outline can be followed at this stage as well as in any other form I have examined; and I find no sign that it participates in the formation of the rod.

For the first few—three or four—sections after the closing of the second nephrostome there is merely a band of cells similar to what I have described in stage "*a*." But further back the cells are arranged so that in the centre of the thickening a definite rod is formed. The segmental duct is rounded and clearly defined, and shows no appearance of dividing (fig. 16). After about ten sections, the rod ceases to be quite distinct, and merges in the cell-mass, which gradually thins down, till it is lost in the ordinary epithelium.

The main conclusions that I draw from the above facts are, (1) that the anterior end of the Müllerian duct is formed from the thickened epithelium plate that spreads from the nephrostomes over the whole surface of the pronephros and beyond it; and (2) that the rod of cells that passes backwards along the segmental duct, and that later becomes the Müllerian duct, arises from a prolongation of this epithelial plate. It seems to me that in the specimen of *Salamandra atra* "B," with its still distinct plates of heightened epithelium round the nephrostomes, and with its posterior process of cylindric cells passing from the second nephrostome along the outside of the segmental duct, we have a stage in the development of the Müllerian duct in which both anterior and posterior are represented.

Before proceeding to follow out the development of the duct I shall consider some of the opinions that have already been expressed as to the first Anlage.

FÜRBRINGER, the first to give a full account of the early stages of the Müllerian duct of an Amphibian, found in *Salamandra maculosa* no appearances that are inconsistent with my view. In his stages "A" and "B," though he says there is no trace of any distinct cord or canal which could be regarded as the Müllerian duct, he yet describes an "inselartige Epithelerhöhung, die mit dem Divertikelepithel Zusammenhängt." In his stage "C," while the right side is as in "A" and "B," on the left side: "zeigt die Stelle des erhöhten Epithels eine kleine Ausbuchtung, an die sich unmittelbar ein solider 0·04–0·05 dicker Strang anschliesst der dem Vornierengang ventral dicht anliegend nach kurzem Verlaufe (während vier Querschnitten) sich in die ventrale Wand desselben verliert." This cord FÜRBRINGER recognises as the "erste Anlage" of the Müllerian duct; but he goes on to say: "Der damit gegebene Fund lässt der Erklärung zwei Möglichkeiten offen: entweder ist der Müller'sche Gang entstanden durch eine successive von vorn nach hinten schreitende Abschnürung von der ventralen Wand des Vornierengangs oder er hat sich gebildet durch eine Wucherung von dem erhöhten Peritonealepithel aus nach hinten, worauf er schliesslich mit der Wand des Vornierenganges verwachsen ist." He decides the difficulty by reference to a later stage, in which he was *unable to examine the posterior end of the cord*, but

in which "der solide Strang, welcher die Anlage des Müller'schen Ganges darstellt, direct dem erhöhten Peritonealepithel anlagert, ohne aber seine Selbständigkeit ihm gegenüber aufzugeben."

The argument seems unsound, inasmuch as it implies that if a duct is derived from the epithelium, it must continue at least for a considerable time to show its connection with it. In the later stage made use of by FÜRBRINGER to settle the point, the development was so far advanced that the Müllerian duct was provided with a fine lumen. I conceive, therefore, that the cord of cells may have been of epithelial origin, as FÜRBRINGER himself thought from his examination of stage "C." The facts do not satisfactorily prove, as FÜRBRINGER maintains, that the origin of the Müllerian duct is independent of the peritonealepithelium: growth backwards from an anterior epithelial thickening is certainly not excluded.

HOFFMANN's description of the processes that precede the formation of the Müllerian duct in Rana and Triton also correspond largely with what I have observed. As to Rana he writes: "Der Müller'sche Gang ist jetzt noch nicht" (at the time of separation of segmental duct and pronephros) "zur Anlage gekommen, bevor dies stattfindet, zeigt das Peritonealepithel, welches den noch bestehenden Theil des Pronephros bekleidet, eigenthümliche Veränderungen, indem es sich in ein hohes schmales Cylinderepithelium umbildet; diese Umwandlung der platten Peritonealzellen in hohe Cylinderzellen dehnt sich lateralwärts noch eine bedeutende Strecke weiter aus als der Pronephros reicht und setzt sich selbst ventralwärts noch fort." And after describing the separation of segmental duct and pronephros, he goes on to narrate that the blind anterior end of the former "legt sich nun dem erhöhten Peritonealepithel des fortwährend mehr und mehr sich zurückbildenden Pronephros an und verlöthet sich mit ihm."

It is subsequent to this, according to HOFFMANN, that the Müllerian duct is originated by a splitting of the segmental duct—or rather of a *small part* of it.

In like manner a cylinder epithelium "neben und zwischen den beiden Trichtern" is described as occurring in Triton, "bevor der Müller'sche Gang sich angelegt hat"; and a splitting of the segmental duct is said to occur at the anterior end.

The division of the segmental duct in Rana is not figured, but it is not difficult to see that a mistake might very readily arise by some "small part" of the Anlage of the Müllerian duct being applied more closely than usual to the degenerating segmental duct.

The splitting in Triton is illustrated, but not so as to carry conviction; the figures numbered "15," "16," and "17" might very well represent a simple change of position of the duct "W.g." from a more dorsal to a more ventral position, and the other series "18" to "20" might likewise illustrate a change in the opposite direction. Time after time I have found similar series in the anterior region of the segmental duct, for where a change of position occurs *the duct not uncommonly doubles back on itself* (*cf.* figs. 3 and 4, and 8 to 11).

I suggest, then, a possible explanation of the published figures. I venture to do

so because, in the first place, the figures themselves indicate a change in position of the segmental duct; and secondly, because I have failed to find in Triton, or in any of the other forms examined by me, appearances such as HOFFMANN shows, *except where there has been a change of position of the segmental duct.* JUNGERSEN, too, has examined Triton carefully without seeing what HOFFMANN describes,—open communication between the segmental and Müllerian ducts.

SEMON, MACBRIDE, and JUNGERSEN all agree in ascribing the entire first Anlage of the Müllerian duct to the cœlomic epithelium.

SEMON says of Ichthyophis: "Im Bereich der Vorniere könnte auf diesem Stadium" (the first in which he found the Anlage) "überhaupt nicht der Vornierengang in Frage kommen da dieser bei seiner enormen Schlängelung unmöglich den schnurgeraden Müller'schen Gang von sich abspalten oder aus einem Teil seiner Wandung erzeugen könnte. . . . Auch in den unteren Abschnitten im Bereich der Urniere, wo der Vornierengang durchaus gestreckten Verlauf besitzt, habe ich an keiner Stelle und auf keinem Stadium je irgend welche Beziehungen des Vornierenganges zur Peritonealfalte aus der sich der Müller'sche Gang bildet, entdecken können."

MACBRIDE in Rana finds a groove in the peritoneum immediately ventral to the one persisting nephrostome of a frog of 28 mm. long.* The "very columnar" epithelium of the groove is continued out over the surface of the pronephros and beyond it; and the groove itself when traced backwards is found to end in a solid thickening of the epithelium.

* MACBRIDE regards this nephrostome as being the first, and not, as HOFFMANN had said, the third, of the nephrostomes of the undegenerated pronephros. And JUNGERSEN takes the same view, though he recognises that the closing is from before backwards in Triton. Both MACBRIDE and JUNGERSEN ground their belief solely on the fact that *the persisting nephrostome is anterior to the glomerulus*, whereas in young forms the glomerulus is situated between the second and third nephrostomes. From the facts already mentioned as to *Salamandra atra* it appears that the position of the glomerulus is by no means constant; but this becomes still more apparent from a study of an anurous form. In *Alytes obstetricans* the younger stages show the glomerulus between the two posterior nephrostomes; but older forms are more or less altered. One specimen of 25 mm. was found by me to have the glomerulus extending from three sections anterior to the second nephrostome, back as far as the opening of the third nephrostome, while another specimen, 39 mm. in length, has *all three nephrostomes anterior to the glomerulus;* and I have observed various intermediate stages. Moreover, in all the types that I have studied, the degeneration of the pronephros itself has been from before backwards; and a remarkable *partial closure* of the anterior pronephros is observable prior to its complete closure; thus there are various quite obvious stages in the degeneration of the nephrostomes, and these appear in succession, first in the anterior nephrostome, and only later in the second, or second and third. I may illustrate the actual process by describing what I have seen in Alytes:—One specimen 36 mm. in length has all three nephrostomes open, but the anterior one does not open directly into the body-cavity; the actual mouth of the funnel has been closed over anteriorly and laterally, so that a transverse section through it shows an apparently blind ciliated tube running close up to the epithelium. A passage, however, is left open posteriorly, and in this case there is a new mouth in the fourth section behind the true nephrostome. The chief noticeable effect is to make the opening *more ventral* as well as more posterior. The posterior nephrostomes open directly into the cœlom. In another specimen, 39 mm. in length, the backward tunnelled passage from the funnel of the first nephrostome is still longer, and forms a perfectly distinct antero-posterior tube immediately under the epithelium. One of 47 mm. in length shows quite similar appearances, while another of 50 mm., in which the anterior of the pronephros has been replaced by blood-spaces, has only two left; and as these occur in the still undegenerate part of the pronephros, it is easy to identify them as the second and third; on one side the *second nephrostome* opens into the body-cavity by a new posteriorly directed aperture. Similar observations on Triton, *Salamandra atra*, *S. maculosa*, and *Axolotl* confirm the view thus arrived at, that a change of position of the mouth precedes a closing of the nephrostomes. As the pronephros shrinks at the same time, a condition that resembles what was described by VAN WYHE for the Selachians is at least led up to though I cannot say I have yet seen actual fusion of the nephrostomes.

JUNGERSEN, too, denied that the segmental duct had any share in forming the Anlage of the Müllerian duct of Rana and Triton, and ascribed it to the peritoneal epithelium; but speaking of Triton he says: "the mouth-part of the Müllerian duct is the first to be laid down, and it is formed from the peritoneal-epithelium; the development of the mouth is not due to the high epithelium on the pronephros between the nephrostomes, for that is inclosed within the capsule of the glomerulus." This seems to me to be only a partial truth. It is the case that the epithelium in the line between the nephrostomes is not converted into the anterior end of the Müllerian duct; but the mouth is formed from the lateral part of the plate of epithelium that first appears between the nephrostomes; and the "capsule of the glomerulus" is simply formed by the combined outgrowths of the lateral wall and the radix mesenterii, and only partly divides the originally simple Anlage. In the frog and Alytes there is no such division, and the anterior end of the Müllerian duct is seen to arise from the lateral part of the simple plate and the backward process that grows along the segmental duct.

In summing up I may say, that though several of the authors referred to above describe the first Anlage as being split off the segmental duct, *all admit that the anterior of the Müllerian duct develops out of the thickened epithelium of the pronephros region, and Hoffman's is the only description that is necessarily hostile to the view that the part of the Anlage immediately posterior to the epithelial plate is a mere backward process of the same.*

Formation of the Anterior Part of the Müllerian Duct.

The first Anlage develops into the complete duct in two modes: anteriorly the epithelial plate that lies on the pronephros forms first a thick band of cells, then a ridge which becomes grooved, and finally closes to form a tube; posteriorly a rod of cells appears in the neighbourhood of the segmental duct, and in course of time gradually becomes hollowed. I shall first give some particulars to illustrate the former mode.

An Axolotl of 37 mm. (γ) shows the anterior end of the Müllerian duct Anlage lying on the *lateral* body-wall, with the secondary attachment of the lung internal to it. In the 18th section it begins to pass behind the lung, having now come to lie dorsally. This is just on a level with the anterior end of the glomerulus of the pronephros. Twelve sections further back, and posterior now to the glomerulus, the band of epithelium approaches the centre, to lie outside the remains of the degenerate pronephros. Six sections to the posterior a very marked thickening of the Anlage is found, corresponding in appearance and probably in position with the cell-mass that appeared lateral to the second nephrostome in β. From this point the Anlage passes back as a thread of cells. A few sections further on the outgrowth of the radix mesenterii comes to an end, and the Müllerian duct Anlage continues its course along the outside of the segmental duct.

Another Axolotl (δ), 45 mm. in length, has likewise a pronephros that is much reduced. The glomerulus is enclosed in a very small dorsal diverticulum of the cœlom, and the pronephros is encompassed by a thick layer of secondary tissue, so that it is considerably below the epithelium. A few sections posterior to the beginning of the glomerulus a very slight middle diverticulum begins; and on the lateral wall of this a thickened plate of epithelium represents the anterior of the Müllerian duct. After seven sections the Anlage comes to be dorsal; and in the 10th it begins to rise up as a ridge, which seems to rest on the outgrowth of the radix mesenterii.* Soon after the twentieth section the glomerulus disappears, and in the twenty-seventh the outgrowth of the radix mesenterii ends. The ridge is furrowed with a groove that becomes deeper as it gets further back, till about the fortieth section the edges of the depression close and form a tube,† and this is continued backwards by a solid Anlage which follows the segmental duct. The segmental duct is at the base of the ridge from the termination of the outgrowth of the radix mesenterii; and posterior to the closing in of the groove it lies within the ridge, and in close proximity to the Müllerian duct.

An Axolotl (ε) 51 mm. in length shows yet a further stage in the development of the anterior end. It illustrates, namely, how the *lateral Anlage* is undermined by a diverticulum of the cœlom, and by unequal growth of the walls of the body-cavity is first drawn into a more antero-posterior line and then ruptured along the external margin, so that the band of thickened epithelium projects free into the cœlom and is attached only by its inner edge; the band becomes grooved, and closes in to form the Müllerian duct in due course. I have been able to follow this process better in *Salamandra atra* than in Axolotl, but the facts that follow bear out the view that the development is similar in both cases.

The Müllerian duct begins as usual in the middle diverticulum of the body-cavity; but in the fourth section the lung becomes free and this diverticulum terminates. At the very beginning of the Anlage the lateral plate is undermined by another diverticulum of the cœlom (fig. 17). After a few sections, however, the epithelial plate loses its lateral connection, and retaining its inner basis, passes back as an oblique process (fig. 18). For eleven sections after the break in the plate appears there is a lateral remnant to show the former connection of the Anlage (*r*, fig. 18). In the twenty-sixth section, in this case, the groove closes: it begins almost at the anterior, but does not become deep, as in "δ," during its short course. The transition from groove to rod here is so gradual that no tube is visible. It is impossible to say with certainty if a considerable portion of the anterior Anlage has gone through the stages of grooving and closing over, because the segmental duct has disappeared and all other local marks; but from a comparison with "δ," it seems probable that this is so.

The development of the anterior end in *Salamandra atra* has already been described up to the stage where, after the suppression of the inner parts of the lateral

* See figs. 5 and 6 in my preliminary account already cited.

† See figs. 7–10 in the above-cited work.

plate, there persisted a thick band running down the middle diverticulum, and passing obliquely towards the middle line before narrowing to a thread, and accompanying the segmental duct (see p. 515). That stage was found in a specimen 37 mm. long; my next size is 40 mm. in length; but as a specimen 46 mm. long represents an intermediate stage in the development of the Müllerian duct, I shall describe it first.

This Salamander has no longer any appearance of a pronephros, but the glomerulus persists. Opposite the anterior end of the glomerulus there is a narrow lateral band of heightened epithelium, representing the anterior end of the Anlage of the Müllerian duct. After fourteen sections the band broadens into a plate and becomes dorsal in position—just opposite the posterior end of the glomerulus. After other fourteen sections the plate covers the whole dorsal aspect, and a diverticulum of the cœlom makes its appearance underneath it. Eight sections are undermined before the lateral margin of the plate loses its connection with the body-wall, just as was described in the case of Axolotl. For about a dozen sections after the breach, the plate continues to project laterally into the cœlom. At this stage a groove appears in the top of the now narrowed plate; but there is no appearance of inclosing, and the ridge gradually passes into a low backward running band. The segmental duct is not visible; and there is only the change of direction, from oblique to antero-posterior, to give any indication of where the "anterior mode of formation" probably ends.

In a *Salamandra atra* of 40 mm. (G) a further stage in the development is shown. There is no longer any appearance of either pronephros or glomerulus. The anterior of the Müllerian duct is again met with on the lateral wall, lying well to the outside of the lung. After the first few sections its inner margin exhibits a curious pointed projection, which at once recalls the remnant already described as left on the lateral wall (in the case of both Axolotl and the last specimen of *Salamandra atra* referred to) when the epithelial plate is ruptured. But here there is no sign of thickened epithelium opposite the projecting side-piece. After about thirty sections, when this projection has disappeared, and the band has become dorsal instead of lateral, the Anlage begins to rise on a ridge which *projects outwards* from the middle line, and through many sections shows its origin by splitting from the lateral wall. After other twenty sections a slight groove appears; and as the posterior is approached the furrow becomes deeper and deeper, and finally closes some thirty sections after the beginning of the groove. The other side of this form is similar to the one described, but the anterior ungrooved region of the epithelium is much shorter, and the inclosing is much further forward.

The explanation of the appearances just described is got from one of my 46 mm. specimens (H). In it, too, the anterior of the Müllerian duct is found projecting inwards, while further back the direction is outwards; here, again, there is an intermediate flat band. The difference is, that in this case the furthest forward part of the duct is not quite so far on in its development as in G, and the actual occurrence of a separation of the Anlage from the *inner* (more dorsal) wall of the cœlomic diverticulum. *So far as the epithelial plate is dorsal, the separation is from the outer*

or lateral wall; in the curve from the dorsal to the ventral position no diverticulum and no splitting appear; in the lateral region a new diverticulum is found, and the epithelial plate loses its inner connection.

Extensive growth of the body-walls is shown by the greatly altered relations of parts, and probably is the cause of these curious processes.

Growth Backwards.

There are four distinct views as to the backward growth of the Müllerian duct in vertebrates: it has been held to arise throughout its whole length by splitting from the segmental duct, or by independent development in the epithelium opposite the segmental duct; it has been said to grow back, without help of either segmental duct or epithelium, from the first Anlage; and it has been suggested that such backward growth was assisted by either the epithelium or the segmental duct. The opinions as to the formation of the posterior end of the Müllerian duct in Amphibians are conflicting.

What FÜRBRINGER says on the subject has already been referred to. He thought there was splitting throughout the whole length.

HOFFMANN was emphatic as to the non-participation of the segmental duct in the formation of the Müllerian duct, *except* near the anterior end. He writes: "Ich habe mehrere Embryonen untersucht bei welchen sich der Müller'sche Gang neben dem Mesonephros über eine oft bedeutende Strecke augelegt hatte, aber weder beim Männchen (Rana, Bufo) noch beim Weibchen (Rana, Bufo, Alytes) habe ich je eine Verschmelzung des Müller'schen Ganges mit dem Wolff'schen Gang gesehen. Einmal angelegt entwickelt sich also der Müller'sche Gang nach hinten selbständig weiter, und zwar höchst wahrscheinlich unter direkter Betheiligung des Peritonealepithels."

SEMON shows that in Ichthyophis the duct develops from a "Periteonalfalte" with which the segmental duct shows "an keiner Stelle und auf keinem Stadium je irgend welche Beziehungen."

MACBRIDE found the duct during development ended in a "slight thickening of the peritoneum"; and JUNGERSEN says of the backward part of the Müllerian duct that it "is seen partly to arise as a direct backward growth from the anterior part, partly with participation of cells in the Müllerian cord and from the epithelium."

As to Amniota, it is interesting to observe, there is much greater difference of opinion: BORNHAUPT maintained independent backward growth in the case of the fowl; WALDEYER, also working with the fowl, found an ingrowing of the peritoneal epithelium; SERNOFF and GASSER denied the existence of any such "Einstulpung" throughout the whole length; and EGLI (rabbit) and BRAUN (reptiles) also saw no connection between the epithelium and the backward growing tube; BALFOUR and SEDGWICK described in the fowl three kinds of backward growth: anteriorly, independent development from

the third groove of the head-kidney, then splitting from the segmental tube, and posteriorly growth by cells "passing from the Wolffian duct" to the distinctly separate Müllerian duct. In later times JANOSIK (pigeon), MIHALKOVICS (duck, fowl, etc.), and NAGEL (man) have supported an independent growth backwards; WIEDERSHEIM (reptilia) has described a growth that recals WALDEYER'S observations; and AMANN, from a study of the sheep, has concluded that increase in length is chiefly due to a proliferation of the cells of the duct, but that *both* the Wolffian duct and the epithelium may contribute.

In Axolotl "β" the short rod already described ends in a simple epithelial thickening, which finally dwindles till it is a one-cell-deep band (fig. 19).

In Axolotl "γ" the course of the rod is frequently interrupted as it passes back. It becomes more or less distinct at intervals; and its posterior is lost in the epithelium.

Axolotl "δ" shows a long open tube passing backwards, but towards the posterior this diminishes greatly in size, and gives place to the usual rod, which again at intervals becomes more or less indistinct, and finally merges in the epithelial thickening that invariably lies outside the Müllerian duct Anlage (fig. 20). The duct of Axolotl "ϵ" likewise dwindles towards the posterior; the small tube is followed by a rod, and it is succeeded by cells, which are at first dense, and further back are much less compact (figs. 21 and 22).

Salamandra atra resembles Axolotl in this respect. In "G" towards the end of the duct there is noticeable variation in the size of the Anlage; and at intervals the short posterior rod loses its distinctness. *At one or two places there is a distinct connection between the rod and the epithelium,* so it is not only at the extreme posterior end that the epithelium contributes to the formation of the duct (fig. 23).

In none of the specimens examined by me have I seen any communication between the segmental duct and Anlage of the Müllerian duct. On the other hand, I have always found the duct-Anlage ending in the epithelium. Independent growth backwards seems to be excluded by this constant relation of the tip: the appearance of independence is given by the fact that almost immediately anterior to the tip the Anlage is found to have become free from the epithelium. The irregularities in the development are also opposed to the view that growth is independent from before backwards: in such a case one would expect a *continuous* development. From the relations in "G" it would appear that the posterior end is lost in the epithelium,—that is to say, that the thickened epithelium is the *first stage* in the development of the posterior part; that *almost at the posterior end* the duct frees itself, or separates from the surrounding cells: this implies that the formation of the rod follows *rapidly* on the occurrence of the thickening, and that this differentiation is *not equally rapid* all along; this is shown by the occurrence of undifferentiated parts a few sections anterior to the already differentiated posterior end.

A backward proliferation of the cells of the rod is not improbable; but I have never seen an independent free termination; and the epithelial thickening always precedes the rod.

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EXPLANATION OF PLATES.

Fig. 1. Transverse section through *Salamandra atra*, 11·5 mm. in length, showing the lateral union of alimentary canal and lung with the body-wall, in the region anterior to the pronephros.

Fig. 2. Section showing the segmental duct of the same salamander passing towards the mid-dorsal line, just posterior to the pronephros.

Figs. 3 and 4. Sections of the segmental duct of the same salamander, showing appearances met with in the region of the spiral twisting of the duct.

Fig. 5. Transverse section of *Salamandra atra*, 13 mm. in length, in the region of the anterior nephrostome.

Fig. 6. Transverse section of the same between the nephrostomes.

Fig. 7. Section showing ciliated depression in the thickened epithelium, posterior to the second nephrostome of the same specimen.

Figs. 8–11. Series from same specimen, showing spiral twist in the segmental duct, posterior to the pronephros.

Fig. 12. Section of *Salamandra maculosa*, 29 mm. in length, showing the thickened epithelium in the region of the pronephros, divided by the backward growth of the lateral attachment of the alimentary canal.

Fig. 13. Section of the same salamander, showing the *undivided* plate of thickened epithelium.

Figs. 14 and 15. Sections of Axolotl of 25 mm. in length, showing the thickened epithelium between the nephrostomes.

Fig. 16. Section of segmental duct and foundation of Müllerian duct in Axolotl, 27 mm. long.

Figs. 17 and 18. Sections of Axolotl of 51 mm. in length, showing the undermining and rupture of the epithelial thickening that represents the foundation of the anterior end of the Müllerian duct.

Fig. 19. Posterior end of foundation of Müllerian duct in Axolotl of 27 mm.

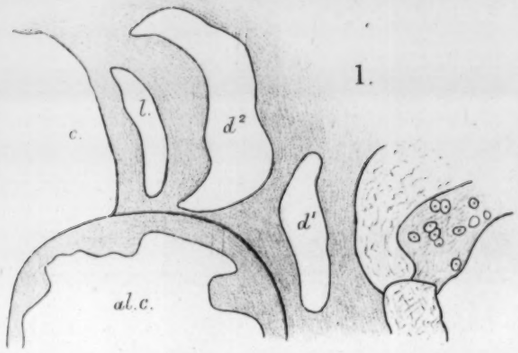
Fig. 20. Section showing the rod-like foundation of the Müllerian duct, merging in the thickened epithelium near the posterior end of the foundation, in an Axolotl 45 mm. long.

Figs. 21 and 22. The same in an Axolotl of 51 mm. in length.

Fig. 23. Section of *Salamandra atra* 40 mm. long, showing non-terminal connection between the rod-like foundation of the Müllerian duct and the thickened epithelium outside the mesonephros.

Ao. = aorta. Al. c. = alimentary canal. Ch. = notochord. C. = cœlom. D^1 = dorsal diverticulum. D^2 = middle diverticulum. L = lung. M. d. = Müllerian duct. Mes. = mesonephros. N^1 = anterior nephrostome. N^2 = posterior nephrostome. Pr. = pronephros. S. d. = segmental duct.

Gregg Wilson on the Development of the Müllerian Duct — Plate I.



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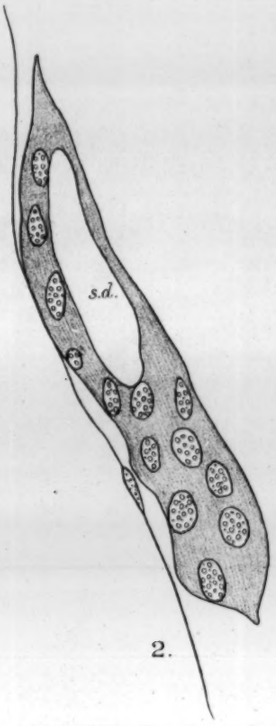

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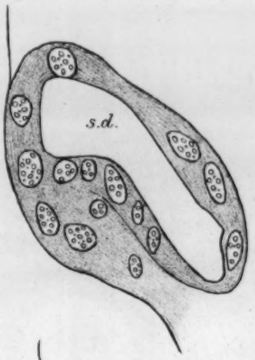

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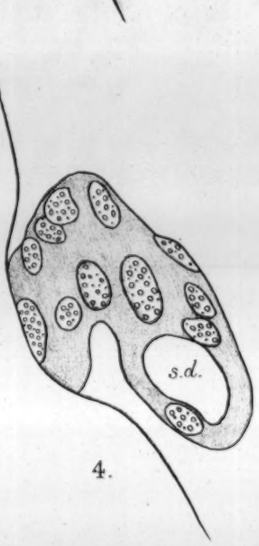

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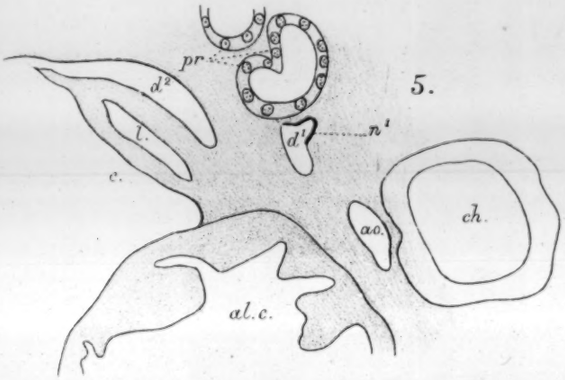

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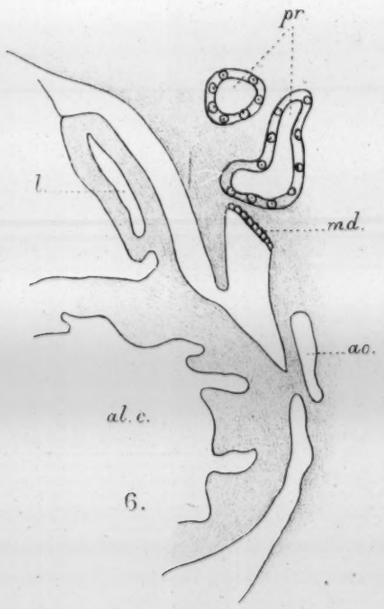

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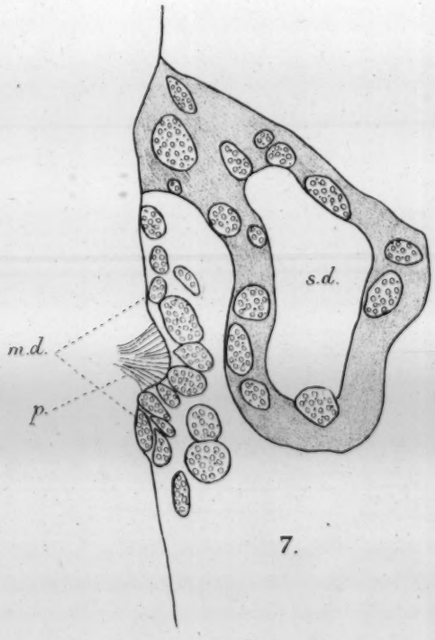

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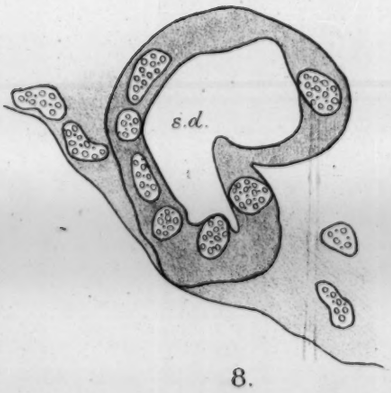

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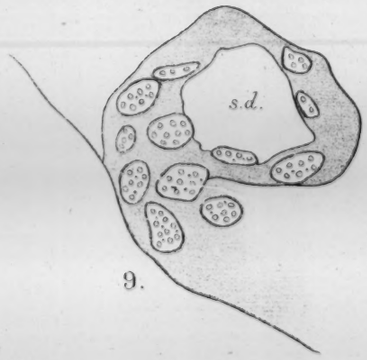

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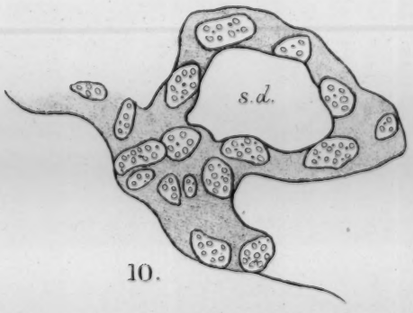

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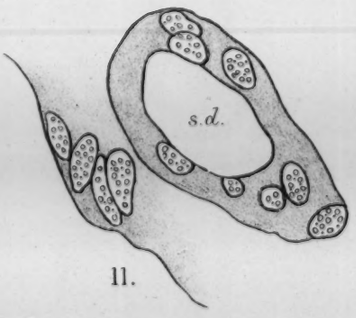

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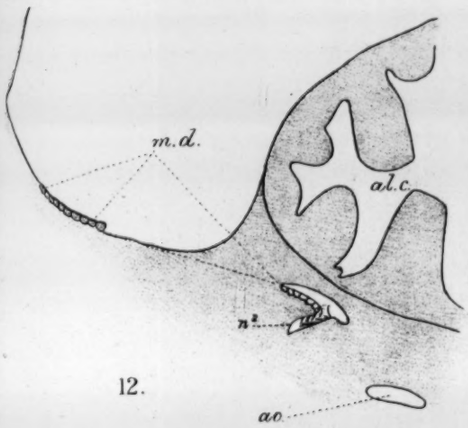
Gregg Wilson on the Development of the Müllerian Duct.—Plate II.



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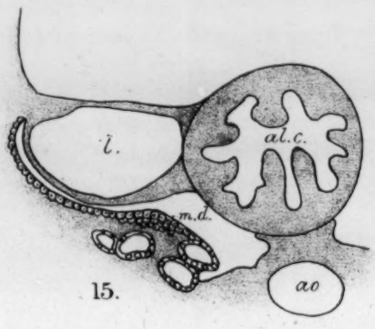

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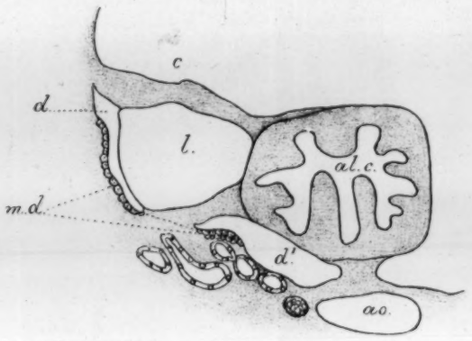

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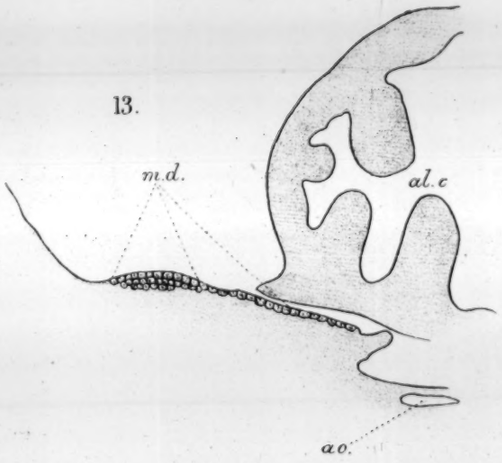

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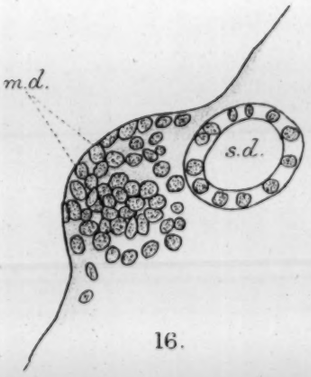

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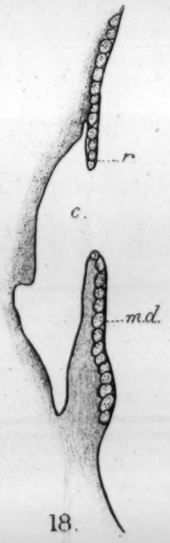

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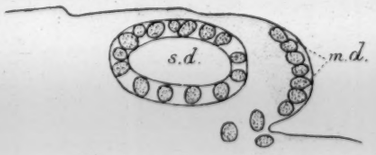

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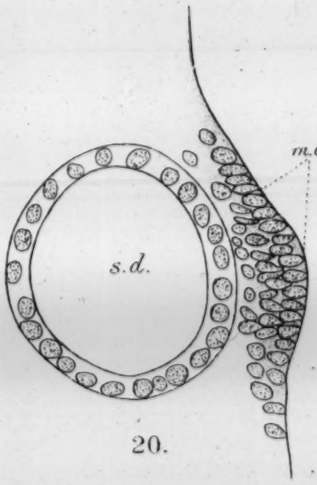

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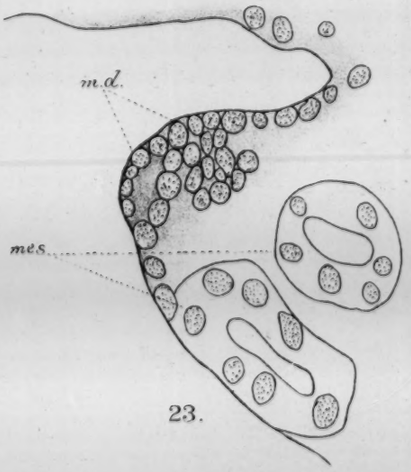

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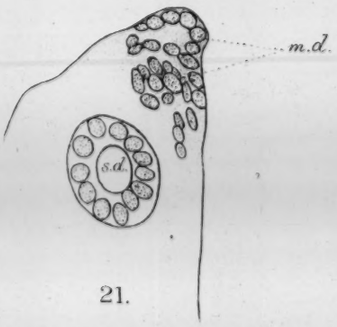

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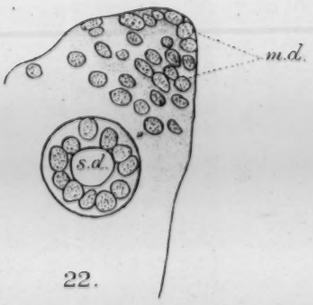

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XIII.—*The Strains produced in Iron, Steel, and Nickel Tubes in the Magnetic Field.* PART I.

By Professor C. G. KNOTT, D.Sc., F.R.S.E. (Plates I.–VI.)

(Read 6th January 1896.)

CONTENTS.

	PAGE		PAGE
§ 1. Introduction,	527	§ 8. The Iron Tubes I. to VII. (Plates I. and II.),	534
§ 2. The Tubes,	528	§ 9. The Steel Tubes I. to VII. (Plates III. and IV.),	536
§ 3. Fixing of Capillary to Tube,	528	§ 10. The Nickel Tubes I. to VII. (Plate V.),	538
§ 4. The Temperature Effect,	530	§ 11. The Other Permanent Tubes,	540
§ 5. Dimensions of the Tubes,	530	§ 12. Complete Cycles and Hysteresis,	542
§ 6. The Magnetic Field,	531	§ 13. Behaviour in Fields of Various Distributions,	546
§ 7. Method of Experiment,	533	§ 14. Conclusion and Summary,	550

§ 1. INTRODUCTION.—On July 20th, 1891, I communicated to the Society a short note on the effect of longitudinal magnetisation on the interior volume of iron and nickel tubes (see *Proceedings*, 1890–91, pp. 315–7). These earliest results of observation of a new and interesting phenomenon in magnetic strains were obtained during my last few months' residence in Japan. In following out the lines of research therein suggested, I have been fortunate in having had placed at my disposal by Professor TAIT the resources of the Physical Laboratory of Edinburgh University. I desire here to record my great indebtedness to him for the interest he has taken in the work, and for his many helpful suggestions. In surmounting the many experimental difficulties met with at every turn, I had the invaluable co-operation of Mr A. SHAND, a senior student in the Physical Laboratory. Various results obtained since 1892 have been communicated in short notes from time to time (see *Proceedings*, 1891–2, pp. 85–88, 249–252; 1893–4, pp. 295–7; 1894–5, pp. 334–5; see also B. A. *Reports*, 1892 and 1893); but it was not possible to regard these as altogether satisfactory. It was only in May of last year (1895) that the many sources of error were finally got rid of, and the apparatus perfected. The present paper deals entirely with the results obtained since then. In these later experiments I was ably assisted by Mr A. C. SMITH, a student in the Physical Laboratory.

A Royal Society grant of £50 enabled me to get a series of tubes of iron, steel, and nickel, all very similar as regards external appearance, but differing in diameter of bore. The tubes of any one metal were formed from pieces cut from the same original bar. There were at first five tubes of Swedish iron, five tubes of Bessemer steel, and three tubes of nickel. Another nickel tube was subsequently made from a bar rolled from the same original casting which supplied the first three tubes. Messrs Henry Wiggin and Co., Birmingham, supplied the long nickel bars to order; and from these the tubes

were cut, turned, and bored by Messrs Aitken & Allan, Edinburgh, who also supplied the iron and steel tubes.

§ 2. The Tubes.—It was hoped that a careful study of the behaviour of these tubes in various magnetic fields would throw some light on the character of the strains accompanying magnetisation in iron and nickel. In the preliminary results for steel and nickel, however, no very evident relation could be detected among the tubes of different bore, other conditions being the same. In the case of iron, a gradation in the law governing the changes of volume was no doubt perceptible as we passed in succession from tube to tube. But, in general, it was evident that the different tubes of any one metal were not identical as regards homogeneity and other physical qualities, notwithstanding the fact that all had been cut from the same bar. There seemed to be, accordingly, only one certain method of studying the influence of bore upon the strain produced in any given field—and that was, to use throughout exactly the same tube. Thus for each metal the tube of narrowest bore was carefully studied, the changes of internal volume at different fields being measured in a way hereafter to be described. This tube was then bored out to a larger diameter of bore, and in this new state similarly treated in the magnetic field. The necessary measurements made, the tube was again bored out to a still larger diameter of bore, and once more subjected to the same treatment; and so on in succession, until the widest bore that could conveniently be used was reached. In this way the absolute identity of material of the walls of the different tubes was secured. From each tube of narrowest bore, six other tubes were formed by successive borings. These are distinguished in the present paper by the numbers I. to VII.* The other tubes of permanent bore, three in the case of each, will be distinguished by the Indian numerals. The particular number chosen for any tube has the same name as the Roman numeral for the tube which is nearest to it in dimensions. Thus the iron and steel tubes have Nos. 3, 5, 7, and the nickel tubes, 1, 4, 7.

§ 3. Fixing of Capillary to Tube.—Each tube was bored out to a short distance from the bottom. In addition to the uniform bore throughout, a wider but shallow part was removed at the top, and a screw cut in it. Into this screw a cap of iron, steel, nickel, or brass could be fitted, and through a central hole in the cap passed the capillary tube, which afforded the means of measuring the change of volume. Much time and thought were spent, and many unsatisfactory experiments were made, before a convenient form of cap was devised. The enumeration of a few of the requirements to facilitate operations, and a few of the most troublesome sources of error which had to be guarded against, together with a brief statement of how these requirements were met and difficulties overcome, will suffice as a description of the final form of cap adopted.

In the first place, it was essential to have a ready means of adjusting the capillary to each tube in turn. In the preliminary experiments with iron the capillary tube was

* These must not be confused with the numbers in the previous notes dealing with the permanent tubes of different bore.

fixed into the hole of the cap by means of marine glue. But this method proved in many ways inconvenient. The plan finally adopted was to provide the cap with a secondary cap or plug, through which the capillary tube also passed. This plug screwed down upon a rubber washer which encircled the capillary tube and which, being squeezed hard against the inner wall of the cap and the outer surface of the capillary, made a water-tight junction between the capillary and the cap.

The cap itself screwed down upon a rubber washer which rested on the ledge or shoulder where the true bore of the tube began. In the earlier experiments the cap was screwed in as tightly as possible so as to compress the washer to the uttermost. But it finally appeared that, however much the washer was mechanically compressed, it could still be compressed a little more when the cap was iron or steel fitted to an iron or steel tube in a high magnetic field. For it was found that with the iron or steel cap much greater *diminution* of volume was obtained than when the brass cap was used. This was clearly due to the iron or steel cap being pulled down hard upon the washer, because of the strong magnetic attraction between it and the tube. A similar effect, though very much smaller, was produced with the nickel cap and tube. The result was, of course, a diminution of volume superposed upon the true effect, and in certain cases quite obliterating it. Unfortunately, this source of error was not detected until Steel and Nickel Tubes No. II. had been bored out. The results for No. I. Steel with the steel cap were utterly untrustworthy and are not here considered. The results for No. I. Nickel have, however, been tabulated, because the false effect is certainly comparatively small.

The simplest way to prevent this mechanical displacement of the cap as a whole was to introduce between the projecting flange of the cap and the top of the tube a brass ring of suitable thickness. It was thin enough to allow the rubber washer to be compressed so as to be water-tight, and thick enough to be in hard contact with both cap and tube.

A similar false effect was also produced when the plug which fixed the capillary to the cap was made of iron, steel, or nickel. Hence, although originally each cap was provided with a plug of the same material, only the brass plug was used in any of the experiments to be here described.

In every case the capillary, cap, washers, ring, and tube were put together under water so as to prevent the retention of any air bubbles. When through haste or carelessness an air bubble happened to be entrapped, its presence was at once detected by the manner in which the change of volume occurred. Instead of a sharp, abrupt motion of the meniscus in the capillary when the magnetic field was applied, there was a slow, gradual motion with a corresponding gradual return on removal of the field. When this happened, the whole apparatus was taken to pieces and carefully put up again.

Before each experiment the capillary tube was carefully cleaned, strong nitric acid and caustic potash being in succession drawn through it. In the preliminary experiments,

before this precaution was systematically taken, considerable trouble arose from the occasional sticking of the meniscus in the capillary.

§ 4. The Temperature Effect.—When the metal tube and part of the attached capillary were filled with water, the whole acted as a very delicate water thermometer. The change of temperature produced by the heating of the magnetising coils caused the meniscus to race across the field of view of the microscope. This motion was, however, almost entirely got rid of by adopting Professor Tait's device. A glass plug was made so as to fill almost entirely the bore of the metal tube. By this means the water in the tube and capillary was reduced so much in bulk that the temperature effect on it was practically eliminated. On the other hand, any effect due to change of volume of the tube was unaffected. It was found necessary, however, to set up the apparatus the preceding afternoon, so that the tube and its contents were reduced to a steady temperature throughout. While thus resting overnight, the end of the capillary dipped in a shallow vessel of water, and was in this way kept quite full until the time of experiment. When the experiment was to be made, the shallow vessel was removed, and the drop at the end of the capillary absorbed by a piece of blotting paper. A gentle downward pressure of the capillary through the rubber washer in the cap pushed out a little of the contained water, which the blotting paper also absorbed. On the pressure being withdrawn, the water in the capillary retreated along its narrow channel, and in this way a meniscus could be formed in any convenient position in the capillary.

The motion of the meniscus was generally observed through a microscope with a micrometer scale. In the case of the nickel tubes in high fields, the displacements were so great as to be most easily measured by eye.

Every capillary used was calibrated, and the observed displacements of the meniscus are all reduced to cubic centimetres. An attempt to increase the sensitiveness of the apparatus by using an exceedingly fine capillary was a complete failure. The effect of viscosity was then so pronounced as distinctly to hinder the motion of the meniscus. The observations here recorded were obtained chiefly with two capillaries, whose cross sections were respectively ·00132 and ·00139 square centimetres.

§ 5. The Dimensions of the Various Tubes are given in the following Tables :—

The Iron Tubes.

No.	Length.	External Diameter.	Internal Diameter.	Volume of Bore.
I.	46·2 cm.	3·84 cm.	·635 cm.	18·81 c.c.
II.	...	...	·953	32·4
III.	...	...	1·270	60·16
IV.	...	...	1·588	94·29
V.	...	...	1·905	130·92
VI.	...	...	2·222	169·76
VII.	...	...	2·696	252·08
3	...	...	1·270	67·7
5	...	...	1·905	127·4
7	...	...	2·540	223·4

THE STEEL TUBES.

No.	Length.	External Diameter.	Internal Diameter.	Volume of Bore.
I.	45·7 cm.	3·84 cm.	·635 cm.	16·7 c.c.
II.	...	...	·953	32·9
III.	...	...	1·270	59·06
IV.	...	...	1·588	91·94
V.	...	...	1·905	128·63
VI.	...	...	2·222	166·55
VII.	...	...	2·696	243·51
3	...	...	1·27	61·93
5	...	...	1·905	127·95
7	...	...	2·540	227·45

THE NICKEL TUBES.

No.	Length.	External Diameter.	Internal Diameter.	Volume of Bore.
I.	47 cm.	4·2 cm.	·635 cm.	17·43 c.c.
II.	...	...	·953	33·57
III.	...	...	1·270	59·77
IV.	...	...	1·588	95·81
V.	...	...	1·905	136·35
VI.	...	...	2·222	173·72
VII.	...	...	2·540	228·6
1	...	...	·635	17·88
4	...	...	1·588	87·58
7	...	...	2·540	224·47

The volume of each bore was measured by weighing the mercury which exactly filled the tube, when cap and capillary were fitted to it as in the magnetic experiment (§ 7).

§ 6. THE MAGNETIC FIELD.—The magnetic field was established by means of a magnetising coil built up of six similar coils of stout copper wire capable of conveying a current of ten ampères. Very rarely, however, did the current exceed three amperes. The coils were made to order for the present series of experiments. They were distinguished by numbers, and were arranged one over the other so as to give as uniform a field as possible in the axial core. The order of arrangement is shown in the following table, which also gives the resistance and number of turns on each coil :—

Coil.	Turns.	Resistance.
No. 4	1771	4·75 ohm.
„ 6	1756	4·83 „
„ 5	1769	4·90 „
„ 3	1765	4·97 „
„ 2	1757	4·80 „
„ 1	1770	4·97 „

Between No. 5 and No. 3 a secondary coil was inserted, by means of which, in connection with a ballistic galvanometer, the total induction across the middle section of the core could be measured. This necessitated these two coils being a little further apart than any other contiguous pair. The field at the middle point of the axis, due to one ampère flowing through the coils for various symmetrical combinations of these, was calculated according to the well-known formula.

In the following table the various symmetrical combinations are represented by *units* and *noughts*—the nought meaning that the particular coil occupying the corresponding position was thrown out of circuit:—

Combination of Coils.	Field at centre due to one Ampère.
111111	173
011110	168
101101	150
110011	27·4
001100	145

The most important of these is the first one—all the coils being included in the circuit, so that any inclosed tube would be subjected to as uniform a field as possible. Even in this case, however, the value 173 does not persist throughout, but diminishes slightly as we pass either way along the axis towards the end coils. It was found by experiment tnat the average values of the fields across the section of the coils at distances 0, 10·8, and 21·9 centimetres measured along the axis from the centre were as the numbers 1, ·971, and ·935. These numbers are proportional to the induced currents obtained in the secondary coil when it was placed at the distances named, no metal core being within the coils. When one of the tubes was inserted, the induced currents were of course greatly increased. At the same time, the average induction across any section diminished very markedly as the distance from the centre increased. In other words, although the tube (which lay well within the coils) was set in a field differing but slightly from uniformity, the magnetisation in the tube varied very greatly as we passed from centre to end.

The following numbers, obtained experimentally when Iron No. 5 was inserted in the coil, show how the total induction across the different sections varies with the position of the section and with the strength of field originally applied. The values of the field are the values at the middle point.

Relative Inductions across Sections of Coil with Tube inclosed, at different Positions and in different Fields.

Distance of Section from Centre of Coil.	For Field		
	463	238	97·5
0	1310	1116	700
10·8	1250	1060	630
21·9	724	532	305

These numbers show at once how very far from a condition of even approximately uniform magnetisation the iron tube is, and afford a good illustration of the manner in which the lines of force leak out of the magnet as we approach the ends. They also show hat there is greater relative leakage in the smaller field. Thus in field 97·5, fully half the lines of force have left the iron at distance 22 centimetres from the middle point; whereas in field 463 there is a leakage of not quite half.

In the face of such large variations of magnetisation from section to section of the

tube, it would be ill-spent labour to attempt in any way an evaluation of the *mean* magnetisation or induction along the tube. The volume changes that are here being studied depend, no doubt, upon the magnetisation rather than upon the magnetising force. And it is not improbable that the complex distribution of magnetisation has a great deal to do with many of the peculiarities of strain which declare themselves and which are discussed below. These considerations convinced me that any attempt to institute a comparison between volume changes and a purely hypothetical estimate of magnetisation could lead to no satisfactory issue. Accordingly in what follows the comparison is, in general, made between volume change and the magnetic field at the centre of the six-fold coil.

§ 7. Method of Experiment.—As already noted, the tube stood vertical in the heart of the magnetising coil. The capillary rose vertically out of the cap high enough to clear the top of the coil, and was then bent into a horizontal position, all except the small part near the end, which was turned down (see § 5). The liquid meniscus was formed in the way above described (§ 5) at a convenient part, and sighted by the microscope. A strong light reflected from a mirror placed beneath rendered the meniscus clearly visible. Its position could be estimated to tenths of the small divisions of the micrometer scale, eighty of which nearly filled the field of view.

The magnetic field was then established, and the resulting displacement of the meniscus noted. On removal of the field, the meniscus moved back towards its original position. When the magnetising force was applied and removed for the first time, the meniscus did not move back to its original position, indicating a permanent change of volume. The same field was then applied in the opposite direction and removed, the corresponding meniscus displacements being noted at every operation. After a few successive applications of this cycle of alternating positive and negative fields, the tube arrived at a steady cyclic condition in regard to the changes of volume. When this cyclic state was reached, the displacements of the meniscus were almost exactly the same both at make and break of the magnetising current. Also, unless some magnetic bias existed in the tube—the after-effect of a previous magnetisation—the amount and direction of displacement were independent of the direction of the magnetic field.* The mean of the four displacements at make and break of the direct and reversed currents is taken as the change of volume due to the corresponding field cyclically applied. It was difficult to get rid altogether of magnetic bias in the lower fields; but by beginning with the highest fields and coming down by small enough intervals to the lower fields, we managed to keep the tube in a fairly neutral condition. On working up again to the highest fields we got practically the same volume change for any given field as was got originally in the descending series. The magnetising current was measured on a Kelvin Long Grade Galvanometer, which was calibrated from time to time *in situ* by direct comparison with a Kelvin Ampere Balance.

Simultaneously with the observations of volume change, measurements were taken

* The earth's vertical field is negligible in comparison with the strong fields necessary to produce the strains here discussed.

on a ballistic galvanometer of the induced current in the secondary coil which surrounded the midway section of the tube. For reasons already explained (§ 6), these observations have not been made much use of.

From time to time a careful study was made of the manner in which the volume went through its cyclic changes as the magnetising force was carried by successive stages through its cycle. Some very remarkable results were obtained, which will be found described in § 12.

I now proceed to the discussion of the results for Iron, Steel, and Nickel, taken in order.

§ 8. The Iron Tubes Nos. I. to VII.—As already stated, these are all successive borings of one original bar. The bore of No. I. was a quarter of an inch in diameter, and each new bore was made an eighth of an inch wider than the preceding one, with the single exception of No. VII., whose bore is $1\frac{1}{16}$ inch instead of 1 inch in diameter.

Each tube was experimented with at least twice (generally oftener)—the iron cap being used in the one case and the brass cap in the other. The results are shown graphically in Plates I. and II. Magnetic field is measured horizontally, and the ordinates give the corresponding changes of volume in 10^{-5} cubic centimetre.

It has not been thought necessary to give the numbers obtained directly by observation. From these, however, the curves shown in the Plates are drawn. To facilitate comparison, changes of volume corresponding to definite fields are here tabulated. The numbers in any column give the volume changes for the corresponding tube. The numbers in any row give the volume changes in the successive tubes corresponding to a definite field.

Iron Tubes with Iron Cap.

Field.	I.	II.	III.	IV.	V.	VI.	VII.
25	+ ·3	+ ·3	+ ·4	+ ·1	+ ·6	− ·1	− ·8
50	+1·0	+1·4	+1·4	+ ·4	+ 1·3	− 1·2	− 4·0
75	+1·2	+1·6	+1·3	0	− ·2	− 1·8	− 3·7
100	0	+ ·2	−1·4	−2·1	− 1·4	+ 1·6	+ 4·7
125	−1·9	−1·6	−3·3	−2·8	+ 3·0	+ 9·5	+12·8
150	−3·1	−2·8	−4·2	−1·1	+ 8·3	+14·2	+18·7
200	−3·8	−2·4	−1·9	+3·2	+12·5	+17·8	+22·6
250	−4·55	−2·7	−1·4	+4·9	+13·8	+19·3	+24·6
300	−5·65	−3·4	−1·4	+5·2	+14·0	+19·8	+25·8
400	−8·55	−5·2	−2·8	+4·4	+13·2	+19·6	+26·6
500	−12	−7·4	−5·3	+3·0	+11·8	+18·6	+27·0

Iron Tubes with Brass Cap.

25	+ ·1	+ ·2	...	+ ·4	+ ·2	+ ·2	− 1·4
50	+ ·4	+ ·6	+ ·6	+ ·7	+ ·2	− ·4	− 4·5
75	+ ·8	+1·0	+ ·6	+ ·6	− 1·3	− 1·8	− 5·5
100	+ ·4	+1·0	− ·4	−1·2	− 2·1	− ·3	+ 2·8
125	−1·2	− ·5	−2·7	−2·2	+ 1·5	+ 7·0	+11·5
150	−2·5	−1·8	−3·4	+ ·2	+ 6·6	+12·6	+16·5
200	−3·0	−1·7	−1·7	+4·3	+12·0	+17·0	+21·1
250	−3·2	−1·4	− ·4	+5·7	+14·0	+19·0	+23·4
300	−3·4	−1·5	+ ·1	+6·2	+15·0	+20·0	+24·3
400	−4·2	−2·0	− ·1	+6·3	+15·3	+20·0	+25·1
500	−5·5	−2·4	− ·6	+5·8	+15·3	+21·0	+25·5

Consider, first, the experiments with the iron cap.

It will be seen at a glance that Nos. I. and VII.—the narrowest and widest bores—have quite opposite behaviours in a series of ascending magnetic fields. The internal space in No. I. begins by increasing in low fields, recovers its original volume in field 100, and thereafter continues decreasing as the field is raised. In No. VII., on the contrary, there is decrease in the lower fields and increase in the higher. Nevertheless, a careful study of the forms of all the graphs reveals that, as we pass from I. to VII. through the intermediate conditions of bore, there is a gradual transition in form from the first to the last. Any contiguous two, in fact, behave in similar fashion, the corresponding graphs presenting similar features, and evidently being of the same type.

Thus No. II. is very like No. I. in the form of its graph, the main difference being a smaller diminution of volume in the high fields. A minimum point, followed later by a maximum, occurs in No. II. soon after the change of sign. To this in No. I. there corresponds a hump, which just falls short of being a true minimum point.

Passing to No. III., we find still smaller negative change and very much more distinct minimum and maximum points than in the case of No. II. After the change of sign the curve still lies wholly below the axis.

But with No. IV. a new feature presents itself—namely, a second change of sign about Field 160. Thus there is increase to Field 75, decrease to Field 160, and increase ever after, up at all events to the highest fields used. But after the second change of sign a distinct maximum exists in Field 300, so that it is possible that a third change of sign may occur in still higher fields. The curve preserves, however, the same general form as that of No. III., the second change of sign being, so to speak, the result of the upward displacement of the curve as a whole.

No. V. presents the same general features as No. IV., the second change of sign occurring in a much lower field.

With No. VI. the initial positive change in low fields has vanished quite away, and with it, of course, the first change of sign. The point at which the change of sign from decrease to increase occurs shifts to still lower fields. This backward drift of the field of zero change continues as we pass to No. VII. Neglecting the initial stages in low fields, we see at a glance that Nos. V., VI., VII. are all of the same type of curve.

Broadly stated, the negative change of volume which is characteristic of the narrowest-bored condition gradually diminishes as the bore is increased, until it is largely replaced by positive change of volume. As this process goes on, the field at which the positive change succeeds the negative change diminishes in value.

When the brass-cap is substituted for the iron-cap, the general character of the phenomena is very much the same. The tendency is for the "brass-cap" curves to be higher than the corresponding "iron-cap" curves. For example, the changes of volume in field 500 for the brass-capped tubes are (with a single exception) all greater positive numbers, or smaller negative numbers, than the corresponding changes for the iron-capped tubes. One particularly interesting case is No. III., the curve of which just comes

above the axis in the vicinity of Field 300. In this instance there are consequently three changes of sign: (1) from positive to negative in Field 93, (2) from negative to positive in Field 290, and (3) from positive to negative in Field 370.

This tendency for the "iron-cap" curves to lie a little lower than the "brass-cap" curves may admit of several explanations. It may, in the first place, be accidental; for the difference between the "brass-cap" and "iron-cap" curves for one tube is no greater than may occasionally be obtained between two "iron-cap" curves obtained from different experiments. It was, indeed, practically impossible to obtain exactly the same series of readings from a second experiment with the same tube set up afresh in (so far as could be judged) exactly the same state. The final screwing in of the cap seemed in some cases to have a slight effect—the harder the screwing in the smaller the volume change. Now the iron and brass caps will differ in the grip they take of the iron tube, and it is quite conceivable that this may give rise to a difference in the volume change under magnetisation.

Then, again, there may be some lingering trace of the false effect discussed in section 3, so that the iron cap, though screwed in as hard as possible, may nevertheless experience a slight bodily displacement towards the tube. This would produce a slightly increased diminution or a slightly diminished increase of volume.

And, finally, there is the question of the average magnetic magnetisation throughout the tube, which will of course be greater and more uniform with the iron cap than with the brass cap. The effect of the iron cap is, in fact, to lengthen the tube a little in one direction. Consequently, the leakage of the lines of induction out of the tube will be somewhat less when the iron cap is used.* In our ignorance of the true character of the strain, which is probably very complicated, it is impossible to surmise in what manner and to what extent a slightly more uniform distribution of magnetisation along the tube will affect the volume change. As will be seen below, the effect of substituting the brass cap for a cap made of the metal of the tube, whether iron, steel, or nickel, was on the whole the same for all.

The dotted curve shown in Plate I. is the graph of No. VII. plotted in terms of numbers proportional to the inductions in the tube instead of the fields. The abscissa 500 on the plate corresponds to an induction at the centre of about 7600. If we take points at the same height on No. VII. graph and on the dotted curve, then multiply the abscissa of the latter by 15·2, we shall get the induction corresponding to the field which is given by the abscissa of the former. All the other graphs, if similarly treated, would be transformed in much the same way, the early portion being greatly drawn out.

§ 9. The Bessemer Steel Tubes Nos. II. to VII.—For reasons already stated, the results for Tube I., being quite untrustworthy, have been omitted. The general features of the volume change are shown graphically in Plates III. and IV. It should be noted that the scale to which the volume change is plotted is double that used in the preceding

* This was proved by experiment.

case. Hence, on the whole, the effect is less pronounced in this kind of steel than in iron. Plate III. gives the results for the steel cap; Plate IV. for the brass cap.

To facilitate comparisons the following tables have been prepared from the graphs. As in the case of the iron, they give the changes of volume for a succession of definite fields.

STEEL TUBES WITH STEEL CAP.

	II.	III.	IV.	V.	VI.	VII.
25	+	+	+	− ·30	− ·74	+
50	+ ·3	+ ·22	+ ·32	− ·62	− 1·16	+ 1·25
75	+ ·85	+ ·80	+ 1·18	− ·18	− ·80	+ 3·4
100	+ 1·25	+ 1·02	+ 2·07	− ·22	− ·30	+ 6·05
125	+ 1·1	− ·38	+ 1·70	− 1·20	+ ·30	+ 8·80
150	+ ·62	− 3·12	+ 1·87	− ·70	+ 1·45	+ 9·80
200	+ ·35	− 3·03	+ 2·69	+ 1·17	+ 4·20	+ 7·60
250	+ ·03	− 2·82	+ 3·59	+ 2·50	+ 6·03	+ 3·40
300	− ·25	− 2·65	+ 4·37	+ 3·50	+ 7·28	− 1·40
400	− 1·29	− 2·72	+ 4·80	+ 4·82	+ 8·80	− 11·80
500	− 3·35	− 3·01	+ 5·10	+ 5·03	+ 9·90	− 20?

STEEL TUBES WITH BRASS CAP.

25	+	− ·1	−	− ·3	− ·7	+ ·1
50	+ ·1	− ·35	− ·1	− 1·1	− 1·55	+ ·6
75	+ ·22	− ·50	− ·05	− 1·50	− 1·90	+ 2·5
100	+ ·50	− ·80	+ ·19	− 1·95	− 2·00	+ 4·8
125	+ ·70	− 1·80	+ ·77	− 2·80	− 1·55	+ 7·16
150	+ ·70	− 2·6	+ 1·4	− 1·9	+ ·85	+ 8·2
200	+ ·65	− 3·8	+ 2·7	+ ·9	+ 3·8	+ 6·3
250	+ ·55	− 2·6	+ 3·8	+ 2·82	+ 5·67	+ 3·4
300	+ ·50	− 1·93	+ 4·6	+ 3·8	+ 7·1	− 1·4
400	0	− 1·4	+ 5·53	+ 5·0	+ 9·1	− 11·4
500	− ·48	− 1·1	+ 6·0	+ 6·2	+ 10·8	− 20·4

It is hardly possible here to trace any well-marked law in the manner in which the volume alters as we pass from tube to tube. And yet—with perhaps the exception of the last two—there is an undoubted resemblance between any contiguous pair. Thus Nos. II. and III. (steel-capped) both show a maximum in field 100–110. From this maximum No. III. falls off abruptly to a minimum in Field 150. No. II. shows no such minimum. But in other respects the graphs belong to the same type.

In like manner there is an obvious similarity between Nos. III. and IV.; and yet in some respects No. IV. is more nearly related to No. II. For the greater part of the range of field No. II. lies between Nos. III. and IV. Thus the successive transitions from II. to III. and III. to IV. are totally unlike one another. Further, any attempt at imagining a law of transition, if such were possible, would be hopelessly confounded when No. V. came to be considered. For, except in the very highest fields, No. V. lies *below* No. IV., just as Nos. II. and III. do. There is, however, a general resemblance in form between Nos. IV. and V., although the latter has a minimum preceding the maximum. This curious undulation does not appear in No. VI., which otherwise, in the

higher fields, is very like No. V. But here again the transition from No. V. to No. VI. differs essentially from the transition from No. IV. to No. V. It is curious to note that, in spite of all this irregularity, the successive tubes from II. to VI. come in order in the very highest fields, No. II. being lowest and No. VI. highest.

But the most extraordinary change is the transition from No. VI. to No. VII., a transition which it is hopeless to bring into line with the other transitions. No. VII. is, indeed, much more like No. II. than any of the others. If it were drawn to one-eighth or one-ninth of its true scale, it would differ very slightly from No. II. But if (§ 5) we compare the volumes of the bores in the two cases, we shall see that the dilatations or changes of unit volume are very much the same; for the volume of No. VII. is nearly eight times that of No. II. This result, however, can hardly be regarded as other than accidental (see APPENDIX). Very remarkable in the case of No. VII. are the comparatively great increase of volume in lower fields and the very great diminution of volume in the higher fields.

The broad characteristics of Plate III. are reproduced in Plate IV., which shows the results when the brass cap is substituted for the steel cap. As in the case of the iron tubes, so here. There is a tendency, especially in the higher fields, for the brass-cap curves to lie higher than the steel-cap curves. In other words, there is a slightly greater tendency to diminution of volume when the tubes are steel-capped than when they are brass-capped. The explanations already suggested in § 8 will apply equally well here.

The greatest deviations in form between the two sets of curves occur in the lower fields. In Plate IV. the curves are smoother in their march than in Plate III. Compare, in particular, the two III.'s and the two V.'s. Had it not been for the curious undulation in iron-capped No. V., the much less marked undulation in the corresponding brass-capped tube's curve might have been ascribed to some flaw in the experiment. It will be noticed that Nos. III. and IV., brass-capped, have diminished volumes in the lowest fields, whereas the iron-capped III. and IV. begin with increase of volume. In our ignorance of the character of the strain produced in the tubes, it is quite impossible to suggest any explanation of these differences in detail.

The complex and inexplicable relations which hold among the successive steel tubes are the more extraordinary because of the comparative simplicity in the case of the iron tubes. In their purely magnetic qualities the iron and steel tubes are very similar, the steel having slightly higher permeability, but neither having any appreciable residual magnetism. Yet they are markedly different in their behaviour as regards strain in the magnetic field. Possibly the iron may be more homogeneous than the mild Bessemer steel; but, however this may be, all the facts serve to show that we are dealing with a very complex set of phenomena.

§ 10. THE NICKEL TUBES NOS. I. TO VII.—The results for the nickel tubes with brass cap are shown graphically in Plate V. To prevent folding of the plate, and yet to keep the scale the same as in the other plates, the nickel curves are represented only to field

400. It is easy, however, to follow out their course in imagination to field 500. The curves obtained for the nickel-capped tubes differ so slightly from those shown, that it was not thought necessary to reproduce them here. A comparison of the numbers in the subjoined tables will meet all requirements.

The brass ring, which was found indispensable in the case of the iron and steel tubes, and the absence of which in Steel Tube I. rendered the observations with it quite untrustworthy, might without serious modification be dispensed with in the case of the nickel tubes. As a matter of fact, Nickel Tubes I. and II. had been investigated and Tube III. bored out before the necessity for the ring was realised. In these cases, however, the differences between the corresponding volume changes in the nickel-capped and brass-capped states are by no means excessive. The effect due to any mechanical motion of the nickel cap because of the attraction between it and the tube must consequently be much smaller in proportion to the true effect than in the case of iron and steel.

NICKEL TUBES WITH NICKEL CAP.

Field.	I.	II.	III.	IV.	V.	VI.	VII.
25	− ·5	+ ·5	+ 1·5	+ 3	+ 5	+ 4·5	+ 3·5
50	− 1	+ ·5	+ 4·0	+ 6·8	+ 10·1	+ 2·2	− 7·5
75	− 4	− 3·2	+ ·5	+ 2	+ 4	− 15·5	− 38·5
100	− 9	− 11·2	− 11·1	− 11	− 11·4	− 46·5	− 75
125	− 16.8	− 26	− 30·5	− 30·5	− 33·5	− 81	− 116·5
150	− 24·5	− 41	− 49	− 49	− 52	− 109·5	− 143·2
200	− 38	− 59·2	− 82	− 82	− 82	− 156	− 179
250	− 44·5	− 69	− 101	− 103·5	− 101	− 182·5	− 201·2
300	− 49	− 74·2	− 112	− 116	− 111·7	− 202	− 208·5
400	− 55	− 83	− 124	− 127·6	− 121·6	− 222	− 225
500	− 58	− 90·5	− 130	− 132	− 127	− 224	− 228·5
			NICKEL TUBES WITH BRASS CAP.				
25	+ ·5	+ ·1	+ 2	+ 5	+ 6·5	+ 4	+ 3
50	+ ·8	+ 1·5	+ 4·5	+ 7·5	+ 11	+ 2·5	− 4·5
75	− ·2	+ 1	+ 1·5	+ 4·5	+ 5	− 19·3	− 35
100	− 5	− 6	− 9	− 9	− 10	− 51	− 71
125	− 12	− 15	− 27	− 27	− 30	− 85	− 106
150	− 19·5	− 27	− 44	− 46	− 48	− 115	− 135
200	− 35	− 47·5	− 76	− 78	− 77	− 158·5	− 175
250	− 45	− 62	− 99·5	− 101	− 98	− 184	− 197
300	− 49·5	− 64	− 116	− 116	− 110	− 200	− 213
400	− 53	− 83	− 131	− 132	− 122	− 213	− 228·5
500	− 55·5	− 85	− 138	− 140	− 128	− 219	− 233·5

It will be seen at once that in all fields higher than 100 there is diminution of volume, and that on the whole the volume change increases with the bore. In the majority of cases there is an increase of volume in low fields. The transition from tube to tube does not follow a very regular law. Nos. III., IV., and V. differ so slightly that they might easily have been different observations with one and the same tube. In the case of both the brass cap and nickel cap the same peculiarity is shown. In low

fields No. III. lies lowest and No. V. highest; but in the highest fields No. V. lies highest and No. IV. lowest. The curves, in fact, all cross one another in the intermediate fields.

The curves on Plate V. are plotted to a vertical scale only one-tenth of the scale used for the steel curves. In other words, the changes of volume in the nickel tubes are on the whole much greater than the corresponding changes in the iron and steel tubes. This is in accord with the well-known fact, that the changes of length of nickel rods when magnetised longitudinally are much greater than the changes of length of iron rods.

Again, the generally opposite characters of the strains in iron and nickel are worthy of note. In low fields there is decrease of volume in the one and increase in the other; in high fields this is simply reversed. In this respect also the results are in accord with well-known results in allied fields of research.

The dotted curve shown on Plate V. is the curve of No. VII. plotted in terms of inductions instead of fields. As with the corresponding curve on Plate I., the early portion is drawn out along the horizontal. The dotted curve meets No. VII. at Field 500 in the latter. This corresponds to induction 3500 across the middle section of the tube. The average induction throughout the whole tube is of course considerably smaller.

§ 11. The Other Permanent Tubes.—The following tables contain the reduced observations for the other tubes, which are distinguished by the Arabic numerals:—

Volume Changes in 10^{-5} Cub. Cm.

Field.	Iron.			Steel.			Nickel.		
	No. 3.	No. 5.	No. 7.	No. 3.	No. 5.	No. 7.	No. 1.	No. 4.	No. 7.
15	–	...	...	...	...	– ·8	...	–	+ ·4
25	–	– ·9	– ·5	+	+	– 2·5	...	+ ·2	– ·4
50	– ·1	– 3·0	– 6·1	+ ·8	+ ·7	– 4·4	– ·1	– 2·6	– 21
75	– ·3	– 8·9	– 14·4	+ 1·6	+ 1·4	– 7·5	– 2·3	– 15·2	– 91
100	– 5·3	– 18·8	– 15·9	+ 2·2	+ 2·6	– 6·7	– 8·2	– 35·8	– 123
150	– 14·1	– 21·3	– 10·2	+ 1·0	+ 8·7	+ 4·8	– 24·5	– 63·9	– 192
200	– 15·7	– 18·0	– 8·9	+ 2·0	+ 16·0	+ 11·8	– 38·3	– 79·4	– 239
300	– 18·0	– 18·8	– 7·4	+ 3·6	+ 27·4	+ 17·2	– 50·9	– 92·4	– 273
400	– 22·3	– 20·7	– 6·9	+ 3·3	+ 33·7	+ 21·9	– 60·5	– 96·7	– 280
500	– 25·0	– 22·6	– 7·5	+ 2·4	+ 36·8	+ 23·8	– 63·4	– 97·5	– 287

In all these cases the cap was of the same material as the tube. The results for the same tubes with the brass cap differ in detail from these in a manner very similar to what was found with the other tubes.

Consider, first, the group of iron tubes, and compare them with the corresponding tubes in the previous table (§ 8). The differences are very striking. With Nos. 3, 5, and 7, there is always *diminution* of volume; whereas in the previous cases there was increase in certain fields, decrease in others. Nos. III. and 3 present least divergence in type, but the change of volume is numerically much greater in the latter. Nos. 5 and 7,

however, differ in a very marked manner from Nos. V. and VII. It is only through a comparatively small range of field that there is diminution of volume in the two last named; while in high fields both are characterised by comparatively large increase of volume. A glance at the corresponding columns in the two tables will show how different may be the behaviour of tubes cut from the same bar and almost identical in form and dimensions.

It will be noticed that No. 7 differs from No. 5 in much the same way as Nos. VII. and V. differ. The tube with the higher numerical designation has either a greater positive or a smaller negative change of volume than the tube with the lower distinguishing number. If we subtract the volume changes of each No. *Five* from those of the corresponding No. *Seven* in the same fields, we get two series of numbers remarkably alike, as in the following table. The first row gives the fields, the second row the differences of the corresponding volume changes of Tubes VII. and V., the third row the same numbers for Tubes 7 and 5.

Field.	25	50	75	100	150	200	300	400	500
(VII.) - (V.)	-1·4	-5·3	-3·5	+6·1	+10·4	+10·1	+11·8	+13·4	+15·2
(7) - (5)	+ ·4	-3·1	-5·5	+2·9	+11·1	+ 9·1	+11·4	+13·8	+15·1

The conclusion to be derived from this comparison is, that although Nos. 5 and 7 are different tubes cut from the same bar, they differ from each other in precisely the same way and to almost exactly the same extent as do Nos. V. and VII., which are different stages in the boring out of a third tube cut also from the same bar. The very marked manner in which No. 3 differs from No. III., No. 5 from No. V., and No. 7 from No. VII., shows that different parts of one long bar may undergo appreciably different kinds of strain when subjected to the same magnetising force.

Passing now to the steel tubes, and comparing the results for Nos. 3, 5, and 7 with those for Nos. III., V., VII. in § 9, we see at a glance how wholly different they are. This is hardly surprising when we bear in mind the extraordinary diversity of behaviour in the Tubes I. to VII. themselves. A detailed comparison leads to nothing definite.

Passing, finally, to the nickel tubes, we find much greater similarity between the two groups than in either of the previous cases. Nos. 1 and I., indeed, might easily be different experiments with one and the same tube, the differences in their behaviour being no greater than could be produced by having the cap screwed up a little tighter in the one case. No. 4 differs in detail from No. IV., but they are similar in type; and similarly with Nos. 7 and VII. The general resemblance between the groups is the more striking, inasmuch as Nos. I. to VII. are successive borings of a tube which was not part of the same bar that supplied Tubes 1, 4, and 7. Thus there appears to be greater uniformity in the behaviour of nickel than in the behaviour of either iron or steel.

§ 12. Complete Cycles and Hysteresis.—The changes of volume which are the subject of discussion in the last three sections, are the changes which occur at make or break of the magnetising current, after the tube has been subjected to several applications of the same current in alternating directions. While the necessary observations were being made, the meniscus in the capillary was often seen going through a curious succession of movements before coming to its final position. As an example, by no means the most extraordinary, take the case of Iron Tube No. III. Brass Cap. In Field 467 the diminution of volume was $-\cdot59$ (10^{-5} c.c.); but at the instant of applying the magnetising current the meniscus first moved along the capillary to a distance which indicated an *increase of volume* 15·3, and then rapidly moved back through its original position to the final position of rest. At break of the current the meniscus, in a somewhat similar manner, reached the final position of zero change after a rapid excursion to a point which indicated a *decrease of volume* 9·8. These rapid excursions of the meniscus far beyond the limits of volume change finally indicated gradually diminished in extent as the magnetising current was decreased in intensity. The following are the observations for this particular tube, the behaviour of which may be taken as a fairly average example.

The numbers in the second and fourth columns headed "Excursion" give the changes of volume corresponding to the maximum displacements of the meniscus at the instant of make and break of the current; the third and fifth columns contain the final volume changes at make and break, which have, of course, the same numerical values.

Iron Tube III.: Brass Cap.

Field.	At Make.		At Break.	
	Initial Excursion.	Final Volume Change.	Initial Excursion.	Final Volume Change.
467	+15·3	− ·59	−9·8	+ ·59
364	+13	+ ·10	−9·8	− ·10
288	+10·8	0	−9·8	0
212	+ 8·2	−1·30	−8·2	+1·30
137	+ 5·5	−3·42	−1·6	+3·42
102	+ 3·9	− ·52	−1·3	+ ·52
82	+ 2·9	+ ·52	−1·0	− ·52
69	+ 2·3	+ ·67	−1·0	− ·67
66	+ 1·3	+ ·62	− ·7	− ·62

The first thought that occurs as we study these numbers is, that the initial excursion is due to the volume change passing through its successive stages as the current gradually works up to its steady value. Both magnetisation and volume change lag behind the magnetic field, which, because of self-induction, requires some measurable time to attain its final strength. Now in low fields there is increase of volume. Hence, since a high field in being established must necessarily pass through the lower values, it is quite to

be expected that the initial effect upon the tube will be a sudden *increase* of volume followed very quickly by the final decrease. Then at break of the current there is the further complication of the self-induced current, which in its short-lived intensity may well be supposed to have a peculiar effect on the volume.

But it will be noticed that the *magnitude* of the initial excursion is in all cases greater than the greatest final increase of volume obtained in the low fields, and becomes greater and greater the higher the limiting fields chosen. It thus appears that this effect depends on the immediately preceding magnetic condition of the tube. The cycle, it must be remembered, has been established, and it is on the reversal of the current, either from positive to negative or from negative to positive, that the phenomenon is observed. If the current, after being removed, is put on again in the same direction, the effect is considerably modified, and in certain cases is quite non-existent. It is evident, in fact, that we are face to face with another of those complicated phenomena which depend on the previous magnetic history of the material, and especially on the immediately preceding magnetic condition. Similar effects in the relation of magnetisation to varying loads and of magnetisation to the magnetising forces have been studied by KELVIN, VILLARI, FROMME, AUERBACH, WARBURG, EWING, and others. In a former paper* I have examined the same phenomena in the manner in which iron and nickel wires twist when subjected to longitudinally and circularly magnetising forces; and NAGAOKA† has successfully carried out a like investigation for the elongations and contractions of iron and nickel wires when magnetised longitudinally.

What was demanded in the present case was a study of the cycle of volume changes associated with an imposed cycle of magnetising force. This was done in a considerable number of instances, the field being increased by convenient stages from zero to the chosen positive maximum, then diminished to zero, reversed, increased to the greatest negative value, and finally reduced again to zero. The change of volume produced at each alteration of field was measured, so that the total change of volume corresponding to any stage could be obtained by simply adding together algebraically the successive changes up to that stage. Five examples have been chosen, almost at random, three from the Iron Tubes, one from the Steel Tubes, and one from the Nickel Tubes, all with the brass cap. The cycles are given in full in the table following, and the corresponding graphs are shown in Plate VI.

The first is for Tube No. III.; and it is instructive to compare the limiting ranges of volume change in the slowly described cycle with the abrupt excursions indicated in the table on page 542. The cycle is for the range of field + 220, for which the excursion at make would be about + 8. But the positive maximum in the slowly described cycle is only +1·5. How shall we account for the extra 6·5? Again, as the field is being slowly diminished the volume change passes through a negative value −5·28, which is distinctly less numerically than the excursion at abrupt break, namely −8.

Thus we see that the existence and direction of the excursions at make and break

* *Trans. R.S.E.*, vol. xxxvi. (1891). † *Phil. Mag.*, January 1894.

CYCLES.

Iron III. Brass Cap.		Iron IV. Brass Cap.	
Field.	Volume Change.	Field.	Volume Change.
0	0	0	0
+ 56	+ ·65	+ 67·5	+ 1·63
+ 63	+ ·26	+ 95	− 1·70
+ 75	− ·72	+ 137	− 1·53
+ 108	− 3·16	+ 95	+ 5·97
+ 149	− 5·25	+ 137	− 1·53
+ 220	− 2·48	+ 252	− 2·18
+ 149	− 5·02	+ 67·5	− ·88
+ 108	− 2·74	0	+ ·42
+ 78	− ·62	− 67·5	+ 1·99
+ 63	− ·23	− 99	− 1·92
+ 55	− ·07	− 142	− 1·27
0	+ ·20	− 252	+ 5·41
− 56	+ 1·50	− 142	− 1·11
− 74	+ ·52	− 99	− 2·58
− 107	− 3·06	− 67·5	− ·95
− 152	− 5·35	0	+ ·36
− 220	− 2·74	Same	
− 152	− 5·28	0	0
− 107	− 2·58	+ 40·3	+ ·98
− 71	− ·95	+ 59	0
− 56	− ·62	+ 71	− 1·47
0	− ·13	+ 59	− ·98
		+ 40·3	− ·75
		0	− ·36
		− 40·3	+ ·78
		− 59	− ·20
		− 71	− 1·56
		− 59	− 1·08
		− 40·3	− ·82
		0	− ·16

Steel IV. Brass Cap.		Nickel V. Brass Cap.	
Field.	Volume Change.	Field.	Volume Change.
0	0	0	0
+ 74	+ ·95	+ 46	+ 16·6
+ 110	+ ·36	+ 86	− 1·8
+ 151	+ ·62	+ 124	− 37·2
+ 197	+ 2·83	+ 170	− 77·5
+ 151	+ 1·18	+ 124	− 44·9
+ 110	− ·19	+ 86	− 13·2
+ 74	+ ·17	+ 46	+ 7·4
0	+ ·1	0	+ ·3
− 74	+ ·69	− 46	− 17·9
− 110	0	− 90	− 3·5
− 149	0	− 126	− 39·6
− 197	+ 2·55	− 170	− 78
− 149	+ ·46	− 126	− 46·4
− 110	− ·23	− 90	− 15·7
− 74	+ ·07	− 46	+ 6·9
0	0	0	0

of the magnetising current are quite in accord with the manner in which the volume change goes through its successive values in increasing and decreasing fields. But the rapid excursions are much greater than the corresponding volume changes in the slowly described cycle, a fact which is simply explained as being due to inertia. The tube, in responding to the first effects of the reversed field, is thrown into an oscillation, which momentarily carries it beyond the limit of statical strain.

The arrow heads on the graphs (Plate VI.) indicate the direction in which the cycle is described. The fields are measured horizontally, the changes of volume vertically. Each complete cycle is taken after the cyclic state has been established by repeated applications of the limiting field in alternating directions. The condition at the beginning of the cycle is taken as the zero, although there is no doubt that the tube in this condition is very far from being in a neutral condition. The effect of the recently applied field must still persist in some residual form. The want of perfect symmetry in all the cases shown is due to some magnetic bias existing in the tube—a bias which it is almost impossible to remove, except by heating to a very high temperature. And even when this has been done, the very first magnetising force applied must at once establish a bias in the direction in which it is applied.

It will be seen that the ascending branches of the cyclic graph of Iron Tube III. reproduce the characteristics of the curve in Plate III.—first an increase of volume, then a decrease, which reaches a minimum about Field 150. The descending branches do not show the positive maximum.

In the two cyclic graphs for Iron Tube IV. the same features are evident. The one cycle is for the range of Field ± 71, and the other for the range ± 252. Both were taken on the same day with the tube in exactly the same condition. The graph of the smaller cycle bears an obvious resemblance to the central part of the graph of the larger. But there are very instructive differences. The field for which the volume change is zero is higher in the larger cycle, as is also the field corresponding to the positive maximum. Moreover—and this point I wish particularly to emphasise—the maximum volume change is nearly twice as great in the higher range cycle as in the lower. Here, then, we have reproduced in the slowly described cycles the same peculiarity already noted in the rapid excursions when the cycle is gone through as quickly as possible. Just as the rapid excursion is greater for the higher magnetising force, so the slowly described cycle of volume changes touches a higher maximum when the range of the cycle is greater. The limits of the cycle have a profound influence upon the detailed form of the graph.

The cycle for Steel Tube IV. presents features very similar to those of the Iron Tube cycles—the differences being differences of degree. The first effect as the field is being applied is an increase of volume; and yet if we look at the Table on page 537, or to the curve on Plate IV. we see that in the lowest fields there is decrease of volume. In short, the undulation in the ascending branch of the cyclic graph has no existence in the curve of the same steel tube on Plate IV. In this case, then, the positive maximum is

unquestionably an after-effect. In other cases the same peculiarity was observed, the general character of which may be described as follows: Take any tube, such as Iron VI. or VII. or Steel V. or VI., which shows diminution of volume in the lowest fields, and subject it to a cycle of moderate range. Then every time the field, after having been applied in one direction and removed, is applied in the opposite direction, there occurs as a first effect an increase of volume. When the tube is subjected to repeated applications of the same field without alternation of direction, this initial positive effect is frequently absent altogether, and in all cases is distinctly modified. All such phenomena are evidently illustrations of the lingering effect of pre-existing magnetic distributions; but it is very difficult to understand their full significance.

The cyclic graph of Nickel Tube V. is of the same type as the others, though comparatively simple. The chief difference is that there is no minimum, not even a hint of a minimum. The return branch lies lower than the ascending branch of the curve, and all the branches have maximum points. The line drawn half-way between the ascending and return branches agrees very well with the corresponding curve on Plate V.

As noted above, the initial excursions at make depend in great measure upon the fact of reversal. For example, when Steel No. 3 with brass cap was treated cyclically by the alternating field $\pm$ 150, the volume change was + 1·06, and the initial excursion + 3·27. But when the cycle was established by making and breaking the field 150 always in the same direction, the volume change was + ·65, and the initial excursion − ·33. In other cases the sign of the excursion remained positive, but its magnitude was greatly diminished.

A striking feature associated with the magnetic-strain hysteresis here discussed is the remarkable effect of inertia in causing the tube, when subjected to rapid alterna tions of field, to oscillate far beyond the limit of statical strain. The case seems to be exactly analogous to that of a spring to which a load is suddenly attached. The spring extends nearly twice as far as the extension which would be produced if the load were applied statically.

§ 13. Behaviour in Fields of Various Distribution.—The results discussed in § 11 show that the effects we are studying are profoundly influenced by differences in composition or in heterogeneity so slight as to have little appreciable influence on other physical qualities. Two iron or steel tubes, cut from the same bar and bored out by the same process and to the same extent, seem as diverse as possible in their behaviour in the magnetic field. Increase of volume of bore is the prevailing characteristic of the one; decrease of the other.

But it must be remembered that the measurement of the volume change of the strain throws no light upon the change of *form*, which is no doubt an important feature of the strain. The character of the strain as a whole we should expect to be very complicated. For we know that the elongation of a thin rod uniformly magnetised is not simply related to the magnetising force; how much less simple will the relation

be for a fairly broad bar or tube, whose magnetisation is necessarily very far from being uniform. In the hope of getting further insight into the real character of the strain, I made some measurements with the tubes in fields, which, though symmetrical, were very far from being uniform.

By suitable combinations of the magnetising coils, seven distinct symmetrical distributions of field were obtained. There was (1) the usual combination of six coils altogether; (2) the combination of the four middle coils—symbol 040; (3) a second combination of four, the two end and the two middle ones—symbol 10201; (4) the third combination of four with the two middle coils left out—symbol 2002; (5), (6), and (7), the combinations of pairs—symbols 020, 1001, 100001 respectively. Now, a particular current passing through each of these combinations will produce a particular distribution of field along the tube, a definite distribution of magnetisation in the tube, and a corresponding change of volume. These can all be experimentally determined; or, as is more convenient, the field can be calculated.

The distribution of field along the tube for one ampère flowing in the coils is indicated by the following table, which gives the values of the field at three regions, distant respectively 0, 10·8 and 21·9 centimetres from the middle of the coil.

Coil Combination.	Fields due to 1 Ampère at distances		
	0	10·8	21·9
6	172·5	171·1	160·5
040	167·5	158·6	87·0
10201	150·2	96·4	87·3
2002	27·3	87·2	146·7
020	145·2	83·9	13·8
1001	22·3	74·7	73·2
100001	5·0	12·5	73·5

From the next table some idea may be gained of the manner in which one of the iron tubes becomes magnetised in these different fields. The quantities in the columns headed B_0, B_1, B_2 are the inductions as measured ballistically in a secondary coil placed at the distances 0, 10·8, and 21·9 cm. respectively from the centre of the coil, when the tube is inserted. The neighbouring columns contain the values of the currents in ampères by which the corresponding inductions were produced. Three currents were used for every combination of coils. The combination symbol is entered on the left.

A similar table was made for the corresponding nickel tube; but, as it presented much the same features, it has not been thought necessary to give it.

From a comparison of these tables we see almost at a glance how very different are the laws governing the distribution of field and induction. As already pointed out, the induction in the field produced by the 6 coils falls off more rapidly than the field as the section is taken further from the centre. With combinations 040, 10201, and 020, this leakage of the lines of induction is more marked, as, indeed, we should expect.

But, excepting that the rate of fall-off is on the whole greater in these cases, the induction does not in its variation follow the variation of the field along the tube. For example, with the combination 020, the change of field between the successive positions is very nearly the same. On the other hand, the induction, in its manner of variation from section to section, follows much the same law as in the other combinations just named.

IRON TUBE VII.

Coil Combination.	Amp.	B_0	Amp.	B_1	Amp.	B_2
6	2·68	7480	2·66	7260	2·66	3700
	1·35	6730	1·35	6440	1·31	2780
	·57	5210	·56	4520	·54	1790
040	3·97	7820	3·90	7620	3·90	3590
	2·01	7120	2·01	6760	1·99	2820
	·84	6110	·84	5430	·80	1970
10201	3·99	7710	3·94	6860	3·86	3080
	1·99	6910	2·01	5910	1·98	2280
	·84	5560	·84	4320	·79	1470
2002	3·97	6180	3·94	6920	3·88	4100
	2·03	5540	2·03	5940	1·99	3080
	·85	3110	·84	3290	·80	1720
020	3·83	7670	3·82	6230	3·77	1890
	1·64	6250	1·65	5370	1·63	1500
	·77	4540	·77	3780	·77	1070
1001	3·90	5750	3·90	6420	3·8	3360
	1·64	4510	1·66	5390	1·65	2350
	·84	2440	·77	2740	·78	1280
100001	3·87	2460	3·86	2520	3·79	1940
	1·64	995	1·64	1040	1·63	872
	·84	468	·85	499	·78	425

Again, the field due to combination 2002 is, broadly speaking, an inversion of the field due to 020, being smallest at the centre and greatest near the ends. The induction in this case is somewhat smaller at the centre than at the intermediate section, but falls off markedly towards the ends. In these cases of rapid variation of field, the induction does not vary nearly so rapidly. Indeed, the most uniform distributions of induction are obtained with combinations 2002, 1001, and 100001, which give three of the least uniform distributions of field.

We now pass to the consideration of the volume changes of certain tubes when subjected to these several distributions of field. In the following tables the volume changes are given in the same unit as formerly—10^{-5} cubic centimetre. Each column is headed by the symbol of the coil combination; and in the first column of all are entered the currents in ampères to which the volume changes correspond. These, as in

former cases, are all taken from the curves which were plotted from the observations of experiment.

VOLUME CHANGES.

Current in Ampères.	Combinations of Coils. 6	040	10201	2002	020	1001	100001
			IRON VII.				
·2	− 1·9	− 1·8	− ·6	− ·6	− ·2	− ·1	Very small and doubtful effects.
·4	− 5·8	− 6	− 2·6	− 2·6	− ·8	− ·4	
·6	+ 4	+ 1·4	− 4·5	− 5·4	− 1·8	− 1	
·8	+14·6	+12	+ ·8	− 1·7	− 3·2	− 2·8	
1·0	+19·6	+17·5	+ 8·3	+ 4·1	− 4	− 4·3	
1·25	+22·2	+20·9	+12·2	+ 9·2	− 2·7	− 5·1	
1·5	+23·7	+22·8	+14·5	+11·8	+ 6·6	− 2·4	
2·0	+25·6	+24·7	+17·5	+14·5	+19·2	+13·3	
2·5	+26·9	+25·9	+19·5	+16·4	+24·2	+20·9	
3·0	+27·6	+26·7	+20·7	+17·8	+27·3	+24·7	
4·0	...	+27·5	+22·7	+19·6	+30·6	+28·8	
			NICKEL VII.				
·2	+ 4	+ 4	+ 2	+ 1	+ 1	+ 1	+
·4	− 22	− 17	− 2	+ 4	+ 4	+ 3	+
·6	− 67	− 58	− 21	− 11	− 2	+ 2	+
·8	−113	−103	− 50	− 37	− 18	− 4	+ 1
1·0	−149	−134	− 74	− 60	− 40	− 18	+ 1
1·25	−180	−160	−100	− 81	− 69	− 41	+ 2
1·5	−199	−178	−121	− 97	− 96	− 64	+ 2
2·0	−218	−202	−151	−118	−140	−102	− 2
2·5	−228	−213	−171	−134	−166	−132	− 6
3·0	−234	−220	−186	−145	−181	−152	− 8
4·0	...	−226	−204	−155	−204	−184	− 11

The first thing to be remarked here is the general resemblance throughout the successive columns for each metal. The field in which the volume change alters sign gradually rises as we pass from combination to combination.

Confining our attention to the higher fields, we see that there is a steady diminution of effect with any given current as we pass in succession from one to another of the first four combinations. This quite agrees with what we should expect to be the case, at all events for the first three combinations. For—see the Table of Inductions—these three combinations give rise to distributions of induction of the same type, but of diminishing average value. For the fourth combination (2002) the distribution of induction changes type somewhat, but there is only a very slight fall of the average inductions as compared with the preceding combination (10201). The diminished volume changes are, especially in the case of nickel, too large to be explained merely in terms of the diminution in the average value of the induction. Now, we have just seen that the combination 2002 gives greater uniformity of magnetisation along the tube than do the others. Thus we seem to have an experimental proof of what is highly probable on theoretic grounds, that the variable distribution of induction along the tube has an im-

portant influence upon the detailed character of the strain, appreciably affecting the magnitude of the volume change.

But this conclusion is placed beyond a doubt when we come to examine the behaviour of the tubes with combinations 020 and 1001. Of all the combinations, the combination 020 gives the most variable distribution of induction; and with the higher currents this non-uniformity is sufficient to make up for the diminished magnetisation. It is with this combination, accordingly, that the iron tube experiences the greatest volume change. Also, the manner in which the volume change is growing with increase of current shows that, in all probability, with stronger current the volume change produced with combination 020 would still more markedly exceed the volume changes with the other combinations. This remark applies with equal force to the case of nickel, for which, however, the current is not strong enough to produce a volume change with combination 020 greater than the volume changes with the three first combinations. With both iron and nickel, the smallest volume change with currents 3 and 4 is produced with the combination giving the least variable distribution of magnetisation; and the probability is that, with strong enough currents, the combination (020), which gives the most variable distribution of magnetisation, would produce the greatest volume change.

The effects produced with the last combination of all (100001) are comparatively insignificant, especially in the case of the iron. The magnetic bias of pre-existing magnetisations was very apparent, and the results were of an extremely doubtful character. In the case of nickel, however, fairly consistent results were obtained, the most interesting feature being the comparatively high field in which the volume change altered sign.

Interesting and suggestive though these varied effects are, the general similarity of behaviour of each tube in the different distributions of field is of still greater interest and importance. For it seems to show that, however complex the strain may be in its smaller details, it is in its broader characteristics essentially the same in distributions of field which are very dissimilar. We may accordingly regard the strain as mainly composed of longitudinal and transverse elongations, which, for purposes of comparison, we may assume to be fairly uniform along the tube.

§ 14. Conclusion and Summary.—So far as I am aware, Joule, Barrett, and Bidwell are the only investigators who have studied the *volume* changes due to magnetisation. They all, however, deal with the volume change of the bar, rod, or wire itself, and do not discuss the internal changes of volume of tubes. Nevertheless, there ought to be some relation between their results and mine.

The most recent and elaborate investigations are those of Mr Bidwell. In a paper, read before the Royal Society of London on March 2nd, 1894, he describes certain experiments made on iron rings. These were magnetised in the usual way by anchor ring coils wound round them, and the corresponding changes in length of the diameter of the ring and of the thickness of the metal forming the ring were carefully measured. From these measurements, the elongation (k) along the lines of magnetisation, and the

elongation (l) transverse to the lines of magnetisation were calculated. These were sometimes positive, sometimes negative, and were always small. Hence the dilatation was given approximately by the quantity $k+2l$. I reproduce from Mr BIDWELL's paper the following table in which the dilatations corresponding to various fields are given for two iron rings, annealed and hardened:—

MR BIDWELL'S RESULTS FOR IRON RINGS.

Magnetising force, in c.g.s. units.	Increments and decrements of volume in ten-millionths.	
	Ring I. (annealed).	Ring II. (hardened).
10	−27	−11
20	−42	−20
30	−47	−20
40	−51	−17
60	−51	− 9
80	−48	− 2
100	−46	+ 3
140	−42	+11
180	−39	+17
220	−37	+22
260	−35	+26
300	−32·5	+30
400	−30	+40
500	−29	+44

In both cases there is a maximum *negative* dilatation occurring in fields 50 and 25 respectively. With Ring II. the dilatation changes to positive in Field 85. Do these results in magnitude and general character at all resemble the results of the present paper?

My results must first be reduced to dilatations, and in making the reduction I assume, in accordance with the statement at the end of last paragraph, an approximate uniformity of behaviour all along the tube. Were the strain simply isotropic, then the dilatation would be measured by the ratio of the change of volume included within the bore to the volume of the bore. Reducing accordingly, we get the following tables of dilatations for iron and nickel—the steel tubes because of their extraordinary diversity of behaviour being disregarded. The dilatations are expressed in the same unit as in Mr BIDWELL's table above.

It is evident at a glance that the dilatations for the iron tubes are of the same order of quantity as those of Mr BIDWELL's rings. Before any further comparison can be instituted between his results and mine, it will be necessary to measure the longitudinal elongations of the tubes directly. This I hope to carry out in the immediate future.

On the whole, Mr BIDWELL's values are greater than mine; but this is not surprising when we consider the essential difference in the method of experiment. Moreover, in

his experiments the magnetisation of the ring must have been fairly uniform throughout—a condition very far from being realised in the case of the tubes.

DILATATIONS × 10^7.

Field.	Iron.						
	I.	II.	III.	IV.	V.	VI.	VII.
100	+ 2·1	+3·9	− ·7	−1·3	− 1·6	− ·2	+ 1·1
200	−16	−5·3	−2·8	+4·6	+ 9·2	+10·0	+ 8·4
300	−18·1	−4·6	+ ·2	+6·6	+11·5	+11·8	+ 9·6
400	−22·3	−6·2	− ·2	+6·7	+11·7	+11·8	+10
500	−29·3	−7·4	−1·0	+6·2	+11·7	+12·3	+10·1
	NICKEL.						
100	− 29	− 18	− 15	− 9·4	− 7·4	− 29·3	− 31
200	−201	−141	−126	− 81·3	−56·6	− 91	− 76·4
300	−285	−191	−193	−121	−81	−115	− 93
400	−305	−247	−218	−138	−90	−122	−100
500	−319	−253	−230	−146	−94	−126	−102

The dilatations given above are the average dilatations of the material of the tube along the inner surface in its successive states from the quarter-inch bore to the final inch and sixteenth. Let us assume for the moment that the dilatation in a solid bar at any given distance from the axis is to some extent similar to the dilatation that would exist if the bar were bored out to that distance. There is, of course, little doubt that this is a very crude assumption, for a free surface newly formed quite alters the molecular arrangements in the immediate neighbourhood, and with considerably less restraint there will be greater tendency to form new configurations. Nevertheless, it may be plausibly enough assumed that the dilatations at increasing distances from the axis of a solid bar will follow a law in some respects similar to the law followed by the dilatations in the tubes of corresponding bore. In other words, the numbers tabulated above may be regarded *as at all events giving a hint* as to the condition of strain in the successive cylindrical shells of a solid bar when magnetised.

With this assumption, then, what is the significance of dilatations varying from centre to circumference in the manner suggested by the values tabulated above? In the case of the iron, the dilatation in the higher fields is negative near the axis, but changes to positive at a distance from the axis equal to about one-third the external radius. Now a dilatation following such a law must clearly be associated with a strain involving a change of form of the bar as a whole. Either the originally plain sections must become curved, or the cylindrical surface spindle-shaped or hyperboloidal; or possibly both effects may be present. As soon as part of the bar is removed from the inside, the greater freedom acquired may easily show itself in the greater dilatations obtained. In this way the *magnitude* of the negative dilatation in the case of Tube

No. I. may receive a sufficiently plausible explanation. With the nickel tubes there is no change of sign of dilatation in the higher fields. This would seem to imply that the magnetic strains produced in a nickel bar are of a comparatively simple character. Further discussion of these interesting points must be deferred until direct measurements of elongation have been obtained with the various tubes under the same magnetic influences.

The broad results established by these experiments may be summarised as follows :—

1. The internal capacity of tubes of iron, steel, and nickel, is appreciably altered in strong magnetic fields.

2. Broadly speaking, the tendency is for the iron and steel tubes to show decrease of volume in low fields and increase of volume in moderate and high fields, except with tubes of small bore, where the volume is diminished in high fields also. Other exceptional instances, especially in the case of steel, seem referable to heterogeneity of structure or unequal tempering.

3. On the other hand, the nickel tubes show increase of volume in very low fields and large decrease of volume in all other fields.

4. The greatest decrease of volume in the nickel tubes is nearly 10 times the greatest increase of volume in the iron tubes.

5. The phenomenon of hysteresis is very conspicuous in the march of volume change with magnetic force (Plate VI.). The effects, however, are too complicated to be briefly summarised (see § 12).

6. The great diversity in the behaviour of certain tubes, cut originally from the same bar and bored out to exactly the same extent, shows that the character of the strain accompanying a given magnetisation is profoundly influenced by differences of structure and temper, which have no appreciable influence upon other magnetic qualities.

7. As a rule, the wider the bore of the tube the greater the maximum change of volume. In tubes of fairly wide bores the *dilatations* in strong fields seem to tend to equality.

8. The behaviour of any chosen tube in fields of different distribution shows that the strain is of a complicated character. This and other considerations suggest that each tube, when powerfully magnetised, becomes shaped either like a spindle or like an hour-glass, and that the closing of the end of the tube by means of a cap has an appreciable influence on the magnitude of the strain, as measured by the volume change.

9. The average dilatations are of the order 10^{-6} in the case of iron, and 10^{-5} in the case of nickel.

Appendix (added March 21st, 1896).

While this paper was passing through the press, certain aspects of the phenomenon suggested questions which only experiment could answer. I was accordingly led to make a new series of experiments with Steel No. VII.

The extraordinary manner in which the tube differed from the other and earlier borings has been noted above (§ 9;—see also the curves on Plates III. and IV.). There is not the least doubt that the early experiments of January 2 were correctly interpreted. At the very first observation made I was struck with the fact that the movement of the meniscus in the capillary was in the direction opposite to what the behaviour of the other tubes led me to expect. But the subsequent experiments of January 7th and 8th fully corroborated the early results. It was after that date that I measured the volume of Steel Tube VII. by weighing the filled-in mercury in the usual way.

Steel Tube VII.

Volume Change in 10^{-5} c.c.

Field.	First condition, January 2.	Second condition, March 4.	Third condition (after annealing).
25	+ ·1	− 2·6	−1·45
50	+ ·6	− 7·1	−2·5
75	+ 2·5	−11·4	−2·1
100	+ 4·8	−14·5	− ·5
125	+ 7·16	−13·0	+ ·75
150	+ 8·2	− 9·75	+1·6
200	+ 6·3	− 4·65	+2·5
250	+ 3·4	− 1·2	+2·75
300	− 1·4	+ 1	+2·7
400	−11·4	+ 3·9	+1·9
500	−20·4	+ 5·8	+ ·9

As the early experiment on Steel VII. in different distributions of field had not been so complete as was desirable, I set up the tube again on March 4th. To my amazement the behaviour of the tube was quite altered. Nothing had been done to it within that two months' interval except what was involved in the measurement of its volume by means of filled-in mercury. Yet, whereas formerly there was diminution of volume in high fields and increase of volume in low and moderate fields (see Plates III. and IV.), now there was increase of volume in high fields and diminution in moderate and low fields. The behaviour of the tube was, broadly speaking, reversed. Was it possible that in its first condition, immediately after being bored out, the material of the tube was in a critical and approximately unstable condition, out of which it was, so to speak, shaken by the pressure of the mercury which was subsequently filled in? If so, then it was altogether peculiar to the steel. For Iron Tube No. VII., whose volume

was also measured after the magnetic strain experiments were made, was found on trial to have in no way changed its behaviour.

To see what other changes could be produced, the steel tube (No. VII.) was annealed by being allowed to cool over night slowly in lime from a temperature of a dull red heat. It was then set up in the usual way, and the changes of volume in various fields measured. For purposes of easy comparison the volume changes accompanying definite fields of the tube in its three conditions are given in the immediately preceding table. The second column reproduces the column under VII. (brass cap) of the table on p. 537; the third column gives the results obtained on March 4th; and the fourth column the measurements of March 11th after the tube had been annealed.

A glance at the volume changes in the first and second conditions of the tube shows the extraordinary character of the mysterious change which must have occurred in the molecular stability of the tube. In its second condition the tube behaves more after the fashion that might have been expected, although the magnitude of the volume change is considerably greater than in the case of Tube VI. The effect of annealing is greatly to diminish the magnitude and to make Tube VII. much more like the others. Probably, then, the difficulty of tracing out any marked law of volume change in the transition from tube to tube in the case of steel is due to heterogeneity and unequal tempering in the original bar.

PLATE I.—IRON TUBES WITH IRON CAP.

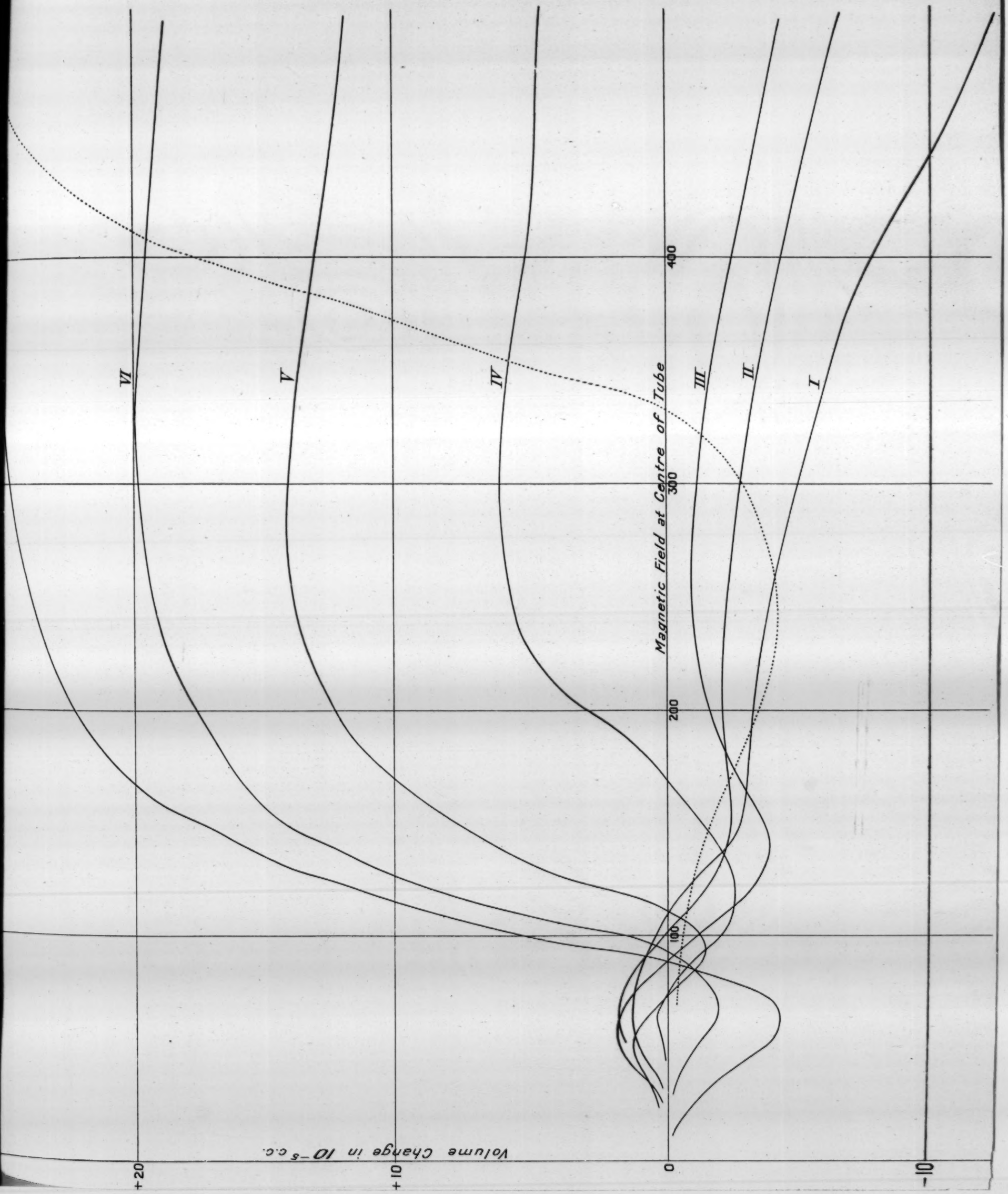


PLATE II.—IRON TUBES WITH BRASS CAPS.

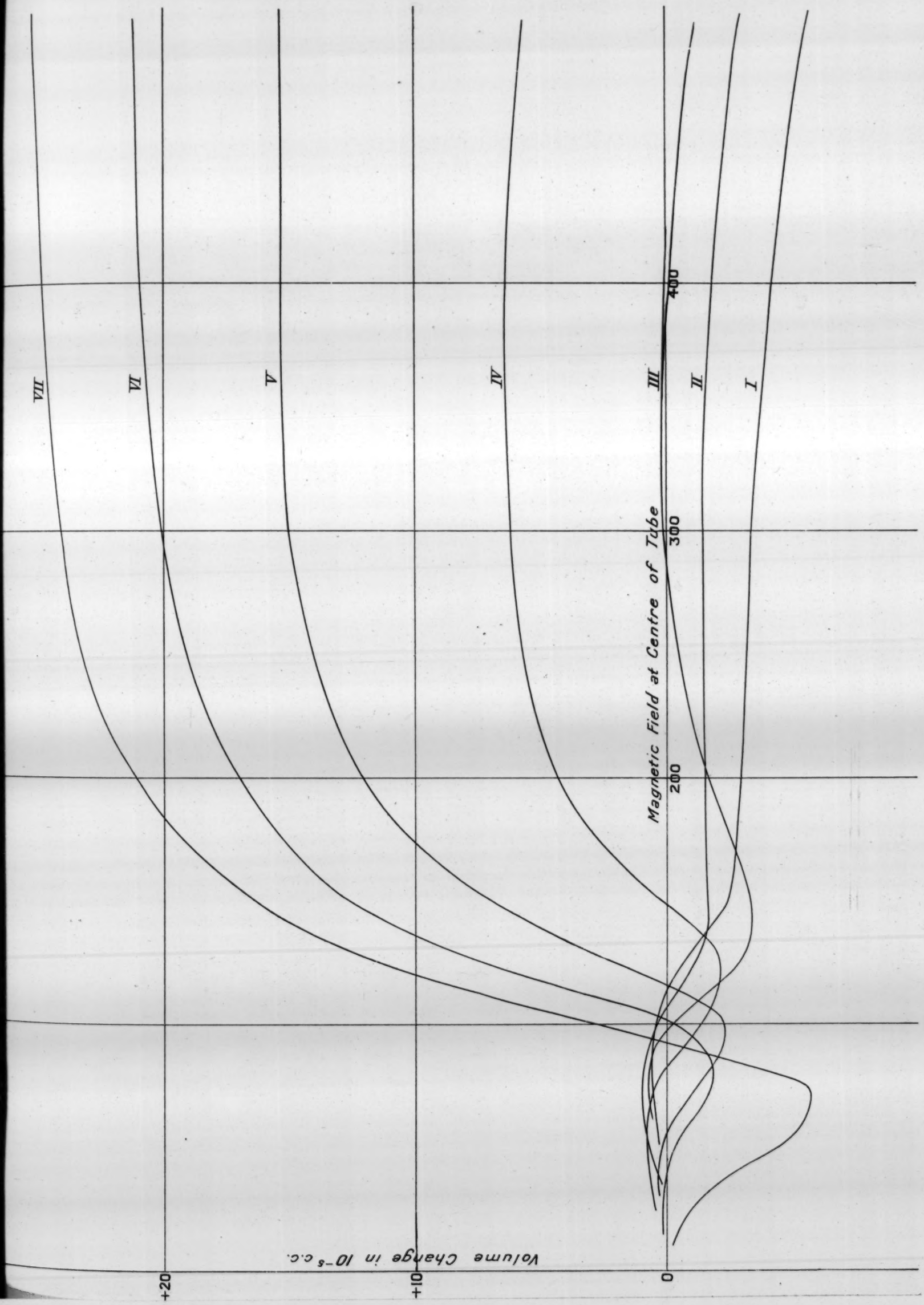


PLATE III.—STEEL TUBES WITH STEEL CAP.

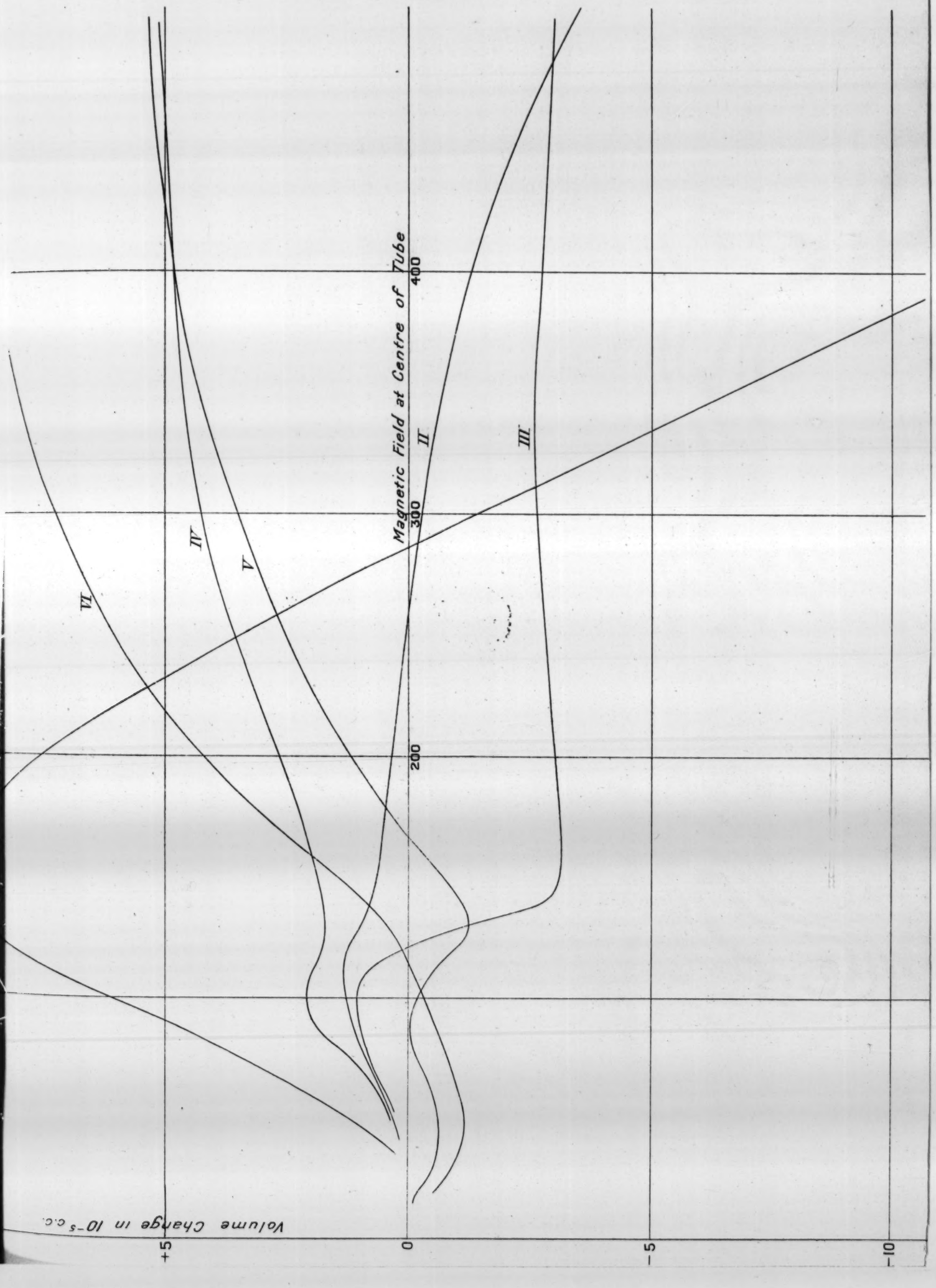


PLATE IV.—STEEL TUBES WITH BRASS CAP.

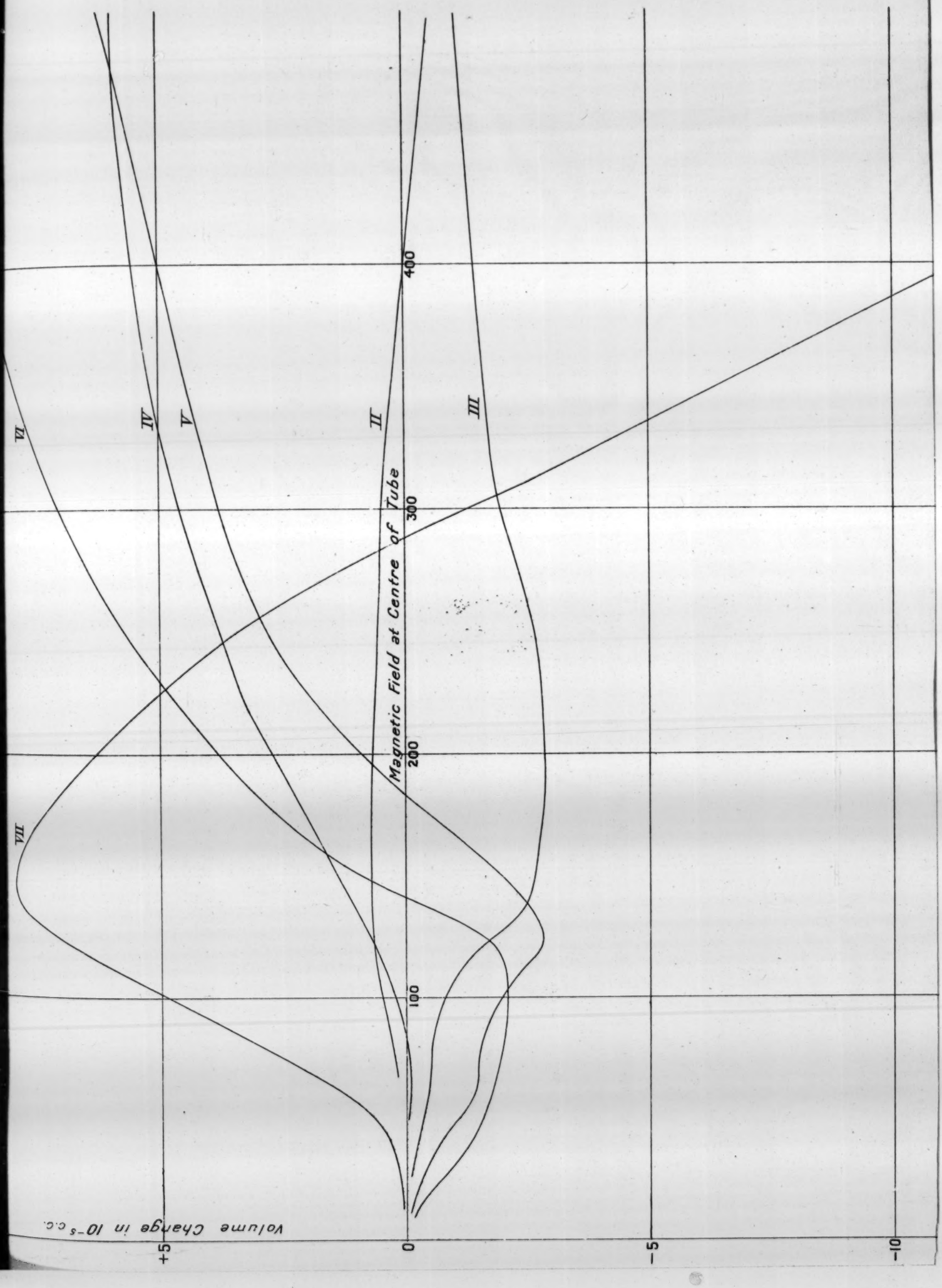


PLATE V.—NICKEL TUBES WITH BRASS CAP.

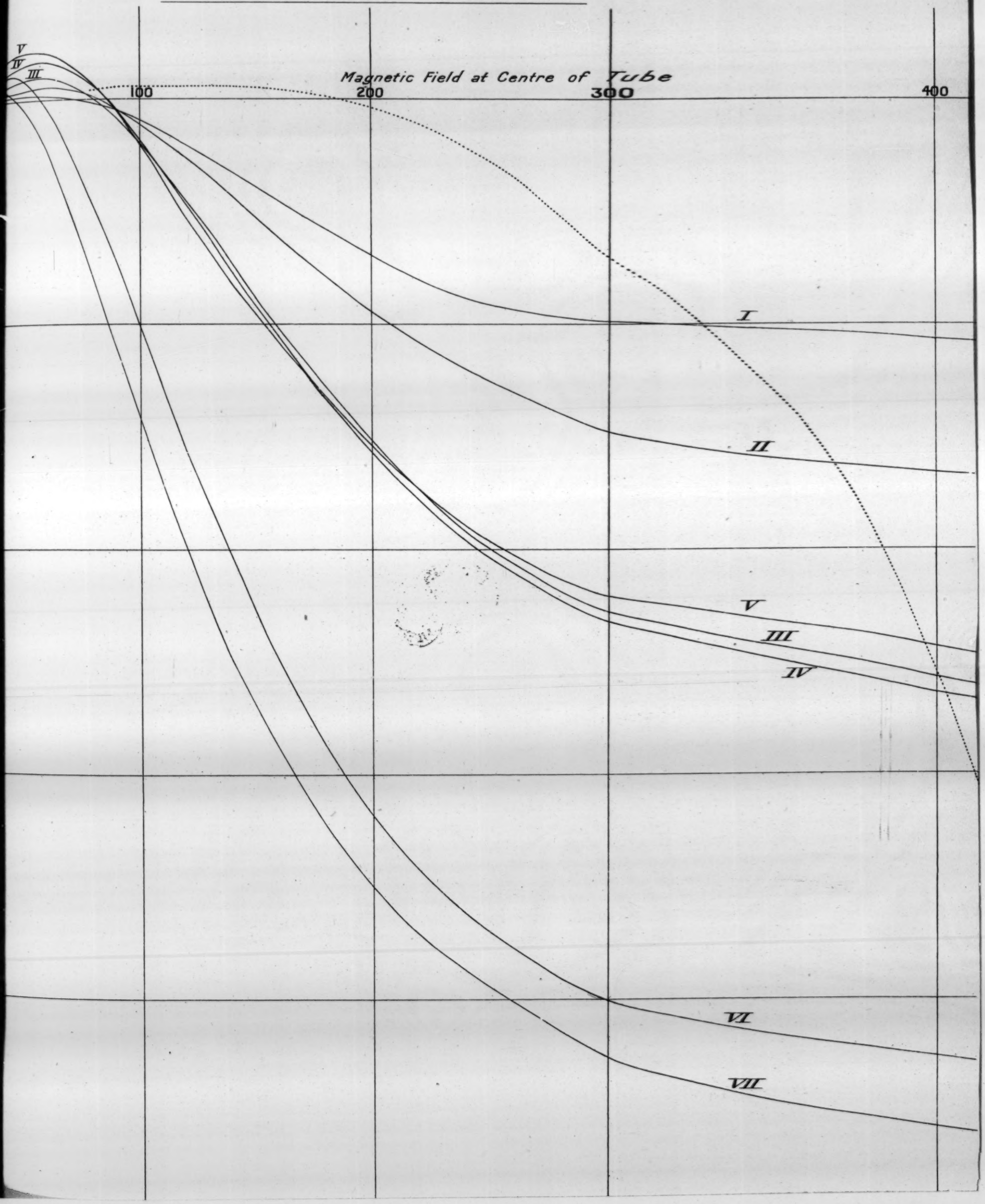
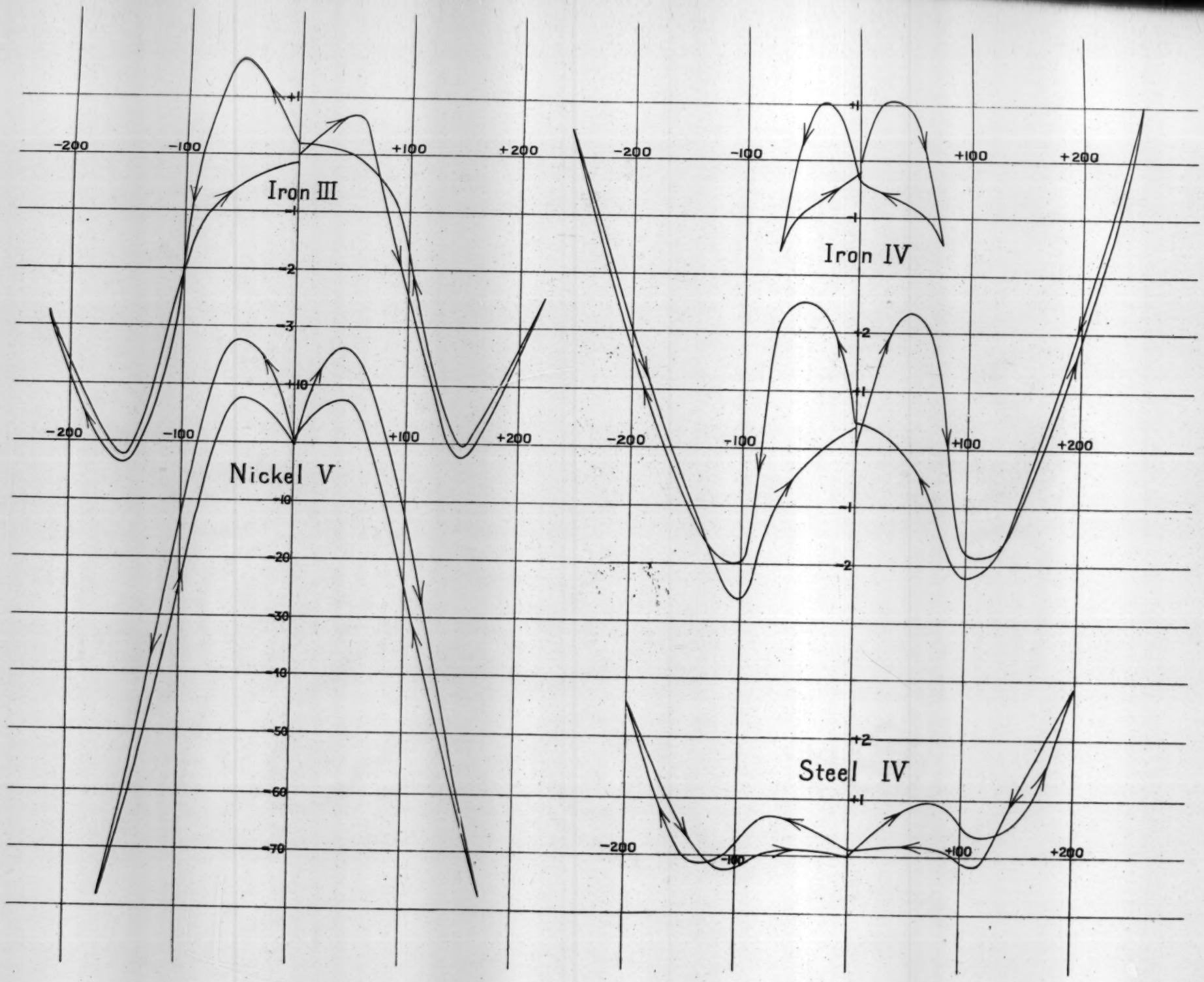


PLATE VI.—COMPLETE CYCLES.



XIV.—*A Revised Description of the Dorsal Interosseous Muscles of the Human Hand, with Suggestions for a New Nomenclature of the Palmar Interosseous Muscles and some Observations on the Corresponding Muscles in the Anthropoid Apes.* By David Hepburn, M.D., C.M., F.R.S.E., Lecturer on Regional Anatomy in the University of Edinburgh. (With a Plate.)

(Read 16th March 1896.)

The main features of the scope of this paper are indicated by its title, from which it will be seen that I do not regard the current descriptions, which appear in text-books of human anatomy, as providing an adequate conception either of the attachments or of the functions of the muscles at present named "Dorsal and Palmar Interosseous." It may seem strange, in connection with such an exact (and, according to some, exhausted) science as human anatomy, that it should be possible to doubt the accuracy of modern text-books concerning such an apparently elementary consideration as the description of a group of muscles in the human hand; but we must bear in mind, first, the ease with which a statement is handed on from author to author without renewed investigation, if only, in the first instance, it has been stamped with the approval of a recognised authority, and second, that these descriptions were originally constructed with little or no reference to the facts of comparative anatomy. It is only by a series of careful comparisons that we can arrive at a proper understanding of the homologies of individual muscles or of groups of muscles in the human subject.

I propose, therefore, to direct special attention to the "Dorsal Interosseous" muscles of the human hand for the purpose of showing that they have been incompletely dissected, and as a result imperfectly described in current anatomical text-books; and that, when this group of muscles is accurately treated, the number of "Palmar Interosseous" muscles is greatly increased, and the palmar group takes its place as the *Intermediate Stratum* of the intrinsic muscles of the manus, and as such should be described under the term Short Flexors of the various digits.

The present views regarding the attachments and functions of these groups of muscles, as recorded in the works of Gray,* Macalister,† Cunningham,‡ and Quain,§ may be briefly summarised as follows :—

First.—There are *four* Dorsal Interosseous and *three* Palmar Interosseous muscles, and the former are larger muscles than the latter.

Second.—Each dorsal muscle possesses two heads of origin, the fibres of which con-

* Gray's *Anatomy, Descriptive and Surgical.*
† Macalister, *A Text-Book of Human Anatomy*, 1889.
‡ Cunningham, *Manual of Practical Anatomy*, 1893.
§ Quain's *Anatomy*, 10th ed., vol. ii. part ii., 1892.

verge in a bipennate manner to a common tendon of insertion. QUAIN* says each dorsal muscle arises "from both of the metacarpal bones between which it is placed, but most extensively from that supporting the finger upon which it acts." This description is endorsed by the other authorities mentioned.

Third.—Each palmar muscle possesses one head of origin, and, according to QUAIN, it arises "from the corresponding lateral surface of the body of the metacarpal bone of the finger on which it acts,"—a statement which closely resembles what is given by other authors.

Fourth.—As regards the functions performed by these muscles, one may say that there is unanimity of opinion so far as the movements of *Abduction* and *Adduction* are concerned. Both of these movements take place in the radio-ulnar or horizontal plane around an antero-posterior axis with reference to an imaginary line bisecting the middle digit, and being prolonged upwards to the wrist,—the dorsal muscles being the *Abductors* and the palmar muscles the *Adductors*. In addition to these actions, however, various writers† claim that the interosseous muscles assist the *Extensors* and *Lumbricales* in producing *flexion* of the first and *extension* of the second and third phalanges.

It is important to note that *flexion* of the first phalanges takes place around a radio-ulnar axis, which is at right angles to the axis in which abduction and adduction occur; and further, that the latter movements are regarded as of primary importance, while flexion is referred to as a secondary action dependent upon their mode of insertion. Now, although we are familiar with movements occurring at an articulation around axes at right angles to each other, as, for example, at the radio-carpal joint, yet such movements are produced by *combinations* of muscles which individually usually act in opposition to each other; and it is rather startling to find that the power of producing movements in two directions at right angles to each other is claimed for an individual muscle.

Turning now to my own dissections of these muscles, it is necessary to observe that the shaft of each metacarpal bone, with the exception of that for the pollex, is described as prismatic, and regarded as presenting a dorsal surface of triangular outline (having the apex towards the carpal end, while the base is directed towards the phalanges), and two lateral surfaces which are separated from each other on the palmar aspect by a smooth ridge occupying the proximal two-thirds of the shaft, but in the distal third of the shaft this smooth ridge bifurcates and leaves a small triangular area towards the head of the metacarpal bone. Muscular fibres do not arise either from the larger dorsal triangular area or from the smaller palmar one. The lateral surfaces are therefore prolonged to both the dorsal and palmar aspects of the shaft, and it is from them that the dorsal and palmar muscles take origin. If we now examine any lateral surface which, according to current descriptions, accommodates the entire origin of a palmar interosseous muscle, and one head of a dorsal interosseous muscle, we shall find the area

* *Loc. cit.*

† (1) QUAIN, *loc. cit.* (2) GRAY, *loc. cit.* (3) DUCHENNE, *Physiologie des Mouvements*, quoted by GRAY and QUAIN. (4) CLELAND (*Jour. of Anat. and Phys.*, old series, i. 85).

very unequally distributed between them, for, whereas the palmar muscle is comparatively powerful, the dorsal head is almost membranous in its dimensions in all the inter-metacarpal spaces except the first; and, since the dorsal muscles—as at present described—project as far towards the palm as the palmar muscles, their difference in size is not so pronounced as one would suppose from an examination of the surface which accommodates a palmar interosseous muscle and one of the heads of a dorsal interosseous muscle. From such a remarkable disparity in the size of the two heads of a dorsal muscle as the foregoing facts elucidate, one might naturally entertain doubts as to whether the larger head was in reality all it is credited with being, viz., dorsal interosseous muscle. These and other reasons have led me to make careful dissections of all the dorsal interosseous muscles of which I could avail myself. Quite recently I have dissected the first half-dozen hands*—representing as many subjects—that were available, in order to test my earlier results, and in every instance my earlier dissections have been verified. These results I shall now proceed to specify in detail.

The feature of a Dorsal Interosseous muscle which I regard as its most distinctive character is the *bipennate* arrangement of its muscular fibres, an appearance best seen from its dorsal aspect, from which point of view it is usually figured. In this respect it presents a marked contrast to the more or less longitudinal nature of the fibres of a Palmar Interosseous muscle. If, however, a careful dissection be made of each Dorsal Interosseous muscle *from its palmar aspect*, then we shall find that each member of the group possesses no small share of longitudinal fibres which do not coincide with the general bipennate arrangement; and although the two sets of fibres are continued to a common insertion, yet the longitudinal fibres maintain their palmar position even at the point of insertion into the first phalanx. In this way, the First Dorsal Interosseous muscle (Abductor indicis) yields a substantial muscular mass whose fibres take origin from the palmar aspect and radial side of the radial lateral surface of the shaft of the second metacarpal bone, just as the First Palmar Interosseous muscle arises from corresponding areas on the ulnar lateral surface of the same bone. Similarly, the Second Dorsal Interosseous muscle (Abductor medii digiti, radiad) yields a set of longitudinal fibres arising from the palmar aspect and radial side of the radial lateral surface of the third metacarpal bone. In the same manner the Third Dorsal Interosseous muscle (Abductor medii digiti, ulnad) and the Fourth Dorsal Interosseous muscle (Abductor annularis v. quarti digiti) yield longitudinal masses which arise from the palmar aspects and ulnar sides of the ulnar lateral surfaces of the third and fourth metacarpal bones respectively. In each instance these longitudinal bundles maintain their palmar positions, although each fuses with and is inserted in common with the dorsal interosseous muscle in front of which each is found, and of which these longitudinal fibres have been regarded as forming an integral part.

At first sight, these detached longitudinal muscular masses appear to increase the number

* My heartiest thanks are due to Sir WILLIAM TURNER for placing his private collection at my disposal for the purpose referred to.

of Palmar Interosseous muscles from three to seven. Now, various forms of increase in the number of Palmar Interosseous muscles have been recorded, and in Professor MACALISTER'S * great work on muscular abnormalities there are references to each of the four longitudinal bundles I am describing. The point of distinction is, that Professor MACALISTER records as abnormalities, structures which I desire to show are constantly present and capable of more or less easy separation in every hand. The fact that under certain circumstances these muscles are so distinct that they have been observed and noted as abnormalities shows that I am not introducing an unknown element into the human hand, although I claim its constant presence as the normal condition.

From this standpoint the questions naturally arise: what position should be assigned to this series of Palmar Interosseous muscles?, and what nomenclature is most applicable to their description?, both of which questions can only be answered by reference to the facts of comparative anatomy. Our knowledge of the comparative anatomy of the intrinsic muscles of the manus is principally based upon Professor CUNNINGHAM'S Challenger Report.† These muscles are divided into three strata, viz., Dorsal, Intermediate, and Palmar. Considered according to the actions performed by them, they are Abductors, Short Flexors, and Adductors respectively. In the human hand the *Dorsal* or *Abductor* stratum consists of six muscles, of which the *Medius* digit possesses two in virtue of its being situated in the middle line of the hand. With the exception of the Abductor pollicis (brevis) and the Abductor minimi digiti, the other members of the group are interosseous in position, and each is bipennate in the arrangement of its fibres.

The *Palmar Stratum* consists of *Adductors* of the various digits. Their principal source of origin is *the middle line* of the hand, but the individual muscles of this stratum are subject to much variation, both as regards number and size, in different animals. In the case of Man, only one member of this group is present, namely, the Adductor pollicis, which, however, has become so specialised that it is usually observed and described in two portions, called *Obliquus* and *Transversus* respectively. The full number of muscles belonging to this group is four, and these may be seen in the *Gibbon*,‡ in which the *Pollex*, *Index*, *Annularis*, and *Minimus* digits are so provided. This entire group has been termed "Contrahentes digitorum."§

The Intermediate Stratum embraces a series of muscles, situated for the most part between the dorsal and palmar strata, and acting as *short flexors* of the various digits. They are generally regarded either as derived from or as producing the members of the dorsal stratum by a process of cleavage or segmentation. Each member of this stratum consists of *two separate portions* or *heads of origin*, which are associated with both lateral surfaces of the shaft of the metacarpal bone which carries the digit upon which

* MACALISTER, "Muscular Anomalies in Human Anatomy," *Trans. Roy. Irish Acad.*, vol. xxv., Science.

† CUNNINGHAM, "*Challenger*" *Reports*, Zoology, v.

‡ HEPBURN, "Comparative Anatomy of the Muscles and Nerves of the Superior and Inferior Extremities of the Anthropoid Apes," *Journ. Anat. and Phys.*, vol. xxvi.

§ HALFORD, *Lines of Demarcation between Man, Gorilla, and Macaque*, Melbourne, 1864.

they act. In the hands of Man and the Anthropoid Apes there is recognition of certain of these facts in current anatomical descriptions, so far as the Pollex and Minimus digits are concerned. Thus we have *M. flexor brevis pollicis* and *M. flexor brevis minimi digiti*, while those other muscles regarded as the incomplete members of this stratum are classified under the title *Palmar Interosseous*, and to them is relegated the action of Adductors.

I shall now discuss those members of this stratum for which the name "Short Flexor" is definitely accepted, and then show how the other individuals of the same group deserve a similar descriptive term in place of "Palmar Interosseous."

M. flexor brevis pollicis nominally possesses two heads,—radial and ulnar,—yet much variation is known to exist, and the ulnar head is not always present in Man, in whom its development and growth may be retarded or altogether prevented by the relatively large proportions and unrestricted energy of the *M. adductor pollicis obliquus et transversus.* Long before the true nature of this ulnar head was clearly established, its presence was regarded as an abnormality, and it was described as the *Interosseous primus volaris of Henle.* Indeed, its recognition by modern text-books is usually confined to a short paragraph under the foregoing designation.

Among the Anthropoid Apes,* the same muscle is subject to similar variation. In my memoir already referred to, I have recorded the presence of both the radial and ulnar heads in the Gibbon and Orang-utan; the rudimentary condition of the ulnar head in the Chimpanzee, and its absence in the Gorilla. My dissection of the Gorilla dealt with the right hand, but I have since dissected the left hand of the same animal, and feeble rudiments of the ulnar head were present. In a recent dissection of a Chimpanzee by Dr DWIGHT,† no trace of this ulnar head of the Flexor brevis pollicis was found.

The *M. flexor brevis minimi digiti*, both in Man and in all the Anthropoid Apes, is described as presenting only one head of origin, viz., its ulnar head; while the radial head, although really present as a constant structure, is artificially detached from its morphological position by a nomenclature which assigns to it the term *Third Palmar Interosseous* muscle. Such a mode of description could only have arisen from regarding the function of a palmar interosseus muscle as quite distinct from that of a short flexor. That the interosseous position does not debar a muscle from being a short flexor is evident from the position of the ulnar head of Flexor brevis pollicis, and therefore there is no serious obstacle in the way of restoring the innermost palmar interosseous muscle to its proper place, and speaking of it as the radial head of the short flexor of the little finger.

Palmar interosseous muscles are therefore presented in their correct anatomical positions when they are considered as members of the *Intermediate stratum* of *short*

* HEPBURN, *loc. cit.*

† DWIGHT, "Notes on the Dissection and Brain of the Chimpanzee, 'Gumbo,'" *Memoirs of the Boston Society of Natural History*, vol. v. number ii. p. 38, 1895.

flexors, and each becomes either the radial or ulnar head of the short flexor muscle of a specific digit.

According to current descriptions there are *three* palmar interosseous muscles in Man's hand, and they occupy the second, third, and fourth inter-metacarpal spaces respectively. In the Gibbon, Orang-utan, and Gorilla a similar number has been described;* but in the Chimpanzee I have recorded the presence of three additional muscles belonging to this series, making a total of six, so disposed as to place two in each of the second, third, and fourth inter-metacarpal spaces; while DWIGHT,† in his recent dissection, has described a total number of *seven*. He says:—"The smallest of these is the first. It arises from the radial side of the metacarpal bone of the index, internal to the belly of the dorsal." . . . . "I have called it a palmar interosseous, because it seems to me a distinct muscle; still its mode of termination gives support to those who would call it a part of the first dorsal."

Whatever may be said concerning the supposed incomplete condition of the short flexor stratum in Man's hand, it must be quite evident that, so far as the Chimpanzee's hand is concerned, there is no occasion to distinguish between short flexors and palmar interosseous muscles, because between them the stratum is completed, and each digit possesses its short flexor muscle presenting a radial and an ulnar head of origin. It must now be abundantly clear that the four palmar slips of muscle, which I have described as capable of being dissected in the human hand, in addition to the three palmar interosseous muscles already accepted, produce a condition exactly parallel to that seen in the Chimpanzee's hand; but, instead of considering them merely as so many additions to the group of palmar interosseous muscles, my opinion is that the nomenclature should be amended so as to conform to accepted facts of comparative anatomy, and that the general term "Short Flexors of the digits" should supersede the present use of "Palmar Interosseous." Thus, each digit would present its short flexor, consisting of a radial and an ulnar head, while the entire series would resemble the dorsal stratum in occupying interosseous positions, with the exception of those portions on the radial and ulnar borders of the hand, viz., radial head of Flexor brevis pollicis and ulnar head of Flexor brevis minimi digiti. In each case, the short flexor would be distinguished by the distinctive name of the digit on which it acted. In this way we should recognise *M. flexor brevis pollicis* as consisting of the *Radial* and *Ulnar* heads at present described.

M. flexor brevis indicis consists of a radial head, separable from the Abductor indicis, and an ulnar head (First Palmar Interosseous). The insertions of these two portions are found in opposite sides of the base of the first phalanx of the index digit.

M. flexor brevis medii digiti consists of a *radial* head, separable from Abductor medii digiti (radiad), and an *ulnar* head, separable from Abductor medii digiti (ulnad). These are inserted into opposite sides of the base of the first phalanx of the middle digit.

* HEPBURN, *loc. cit.* † DWIGHT, *loc. cit.*

M. flexor brevis annularis consists of a *radial* head (Second Palmar Interosseous) and an *ulnar* head, separable from Abductor annularis. These are inserted into opposite sides of the base of the first phalanx of the ring finger.

M. flexor brevis minimi digiti consists of a *radial* head (Third Palmar Interosseous) and an *ulnar* head, which at present appropriates the entire name. These are inserted into opposite sides of the base of the first phalanx of the little finger.

From this description it will be seen that each *Abductor* in the dorsal stratum is intimately associated at its *insertion* with one of the heads of a short flexor, and it is to this association that I attribute the fact that these portions of the short flexors have not hitherto received due recognition. Undoubtedly there are cases when the fusion is more complete than at other times, and hence, under favourable circumstances, *additional* palmar interosseous muscles have been recognised and recorded as abnormalities. In my endeavour to prove the existence of a flexor muscle situated in a position where it is more or less fused with an abductor muscle, I regard it as of great importance that, even by current descriptions, a flexor action has always been claimed for an abductor muscle, situated in an interosseous space, and that the flexor portions, which I consider capable of separation from abductor muscles, always occupy the palmar aspect of the hand. There has never been any difficulty in recognising those portions of the short flexors which possess an independent insertion. From this statement we must except the ulnar head of the short flexor of the Pollex, which has become overshadowed, and in some cases suppressed, by the Adductor pollicis muscle.

It is important to note that there are *three* nerve twigs sent into each interosseous space for distribution to the three separate portions of muscle which I consider each space contains.

These views regarding the strata of intrinsic muscles in Man's hand have been impressed upon me by many careful dissections, and they have led me to re-examine my earlier dissections of the corresponding muscles in the hands of the Anthropoid Apes, especially the so-called palmar interosseous muscles, with the results that I shall now briefly indicate.

In the Chimpanzee the intermediate stratum of short flexor muscles is found at its fullest development, so far as regards the fingers, for, as already mentioned, the Flexor brevis pollicis possessed only a rudimentary ulnar head in my dissection. In this ape, the short flexors separate with perfect ease from the dorsal interosseous muscles, so that each finger is provided with a short flexor presenting a radial and an ulnar head of origin. In the original description of my dissection,* I recorded this condition of parts as existing in the Medius, Annularis, and Minimus digits, but not in the Index. A renewed examination of the dissection, however, convinces me that the *radial* head of *M. flexor brevis indicis* is also present. At the same time, it was more closely adherent to the palmar aspect of the Abductor indicis than any of the other short flexors were to their respective dorsal interosseous muscles.† This fact,

* HEPBURN, *loc. cit.* † *Vide* DWIGHT quoted *ante.*

coupled with the general acceptance of the current text-book descriptions of the dorsal interosseous muscles of Man's hand, led me, in the first instance, to overlook its presence. In this explanation we may also find the reason why different observers have recorded so much variation in the number of palmar interosseous muscles seen in different dissections of the hand of the Chimpanzee. In the Orang-utan and Gorilla the conditions closely approximate to those found in Man. With care it can be shown that each dorsal interosseous muscle carries upon its palmar aspect one head of a short flexor, so closely fused as readily to escape observation, although capable of separation by fair dissection. In the Gibbon, the difficulty of separating the dorsal interosseous muscles from those heads of short flexors fused with them is extremely great, and I cannot claim to have been successful. The difficulty is undoubtedly due to the cylindrical nature of the shafts of the metacarpal bones rather than to the absence of the muscular slips, because in every case muscular fibres, which took no part in forming the bipennate muscle, arose from the palmar surfaces of the shafts of the metacarpal bones. The three so-called palmar interosseous muscles were distinguished without any trouble, because their insertions are independent, and are not obscured by fusion with contiguous muscles, as is the case with certain heads of the short flexors which are inserted in common with the individuals of the dorsal or abductor series.

Conclusions.

1. The shaft of each metacarpal bone, with the exception of the first, presents two triangular areas, a larger on the dorsal aspect and a smaller on the palmar aspect, neither of which affords origin to muscular fibres. It follows, therefore, that the palmar aspects of the various metacarpal bones are more fully occupied by muscles than the dorsal aspects.

2. The dorsal interosseous muscles—which are Abductors in function—are smaller than current descriptions lead us to believe. This is quite in accordance with the comparatively feeble nature of the abductor movements.

3. Each digit is provided with a short flexor muscle presenting radial and ulnar heads which are capable of acting *independently*, and thereby producing a certain amount of abduction and adduction according to their position with regard to the middle line of the hand.

4. Every muscle of the Dorsal or Abductor series is inserted in common with *one of the heads* of a short flexor muscle, and, in consequence of their close fusion, the line of separation between them is somewhat obscured, and has been overlooked.

5. The members of the Palmar or true Adductor stratum have all disappeared from the human hand, with the exception of the Adductor pollicis obliquus et transversus, hence this action has been thrown upon certain heads of the short flexors, and in con-

sequence these heads stand out more distinctly, especially as their insertions are isolated from, and not masked by fusion with, any other muscle, either abductor or adductor.

6. Whenever true Adductor muscles are found, as in certain of the apes, they are inserted in conjunction with those heads of the short flexors which are capable of supplementing this action.

7. In the case of the human Pollex, which possesses the one true Adductor muscle of Man's hand, not only is this muscle inserted in common with one head (the ulnar) of the Flexor brevis pollicis, but in consequence that head is always obscured and in many cases extinguished.

Postscriptum.

I have not yet made an exhaustive examination of the human foot with regard to its intrinsic muscles in the light of the results obtained from the hand, but with due allowance for the narrower and more crowded state of the intermetatarsal spaces, I have no doubt the same conditions prevail there also.

EXPLANATION OF PLATE.

Fig. 1. The *Abductor stratum* of muscles is shown from the dorsal aspect with special reference to the bipennate nature of the Dorsal Interossei.

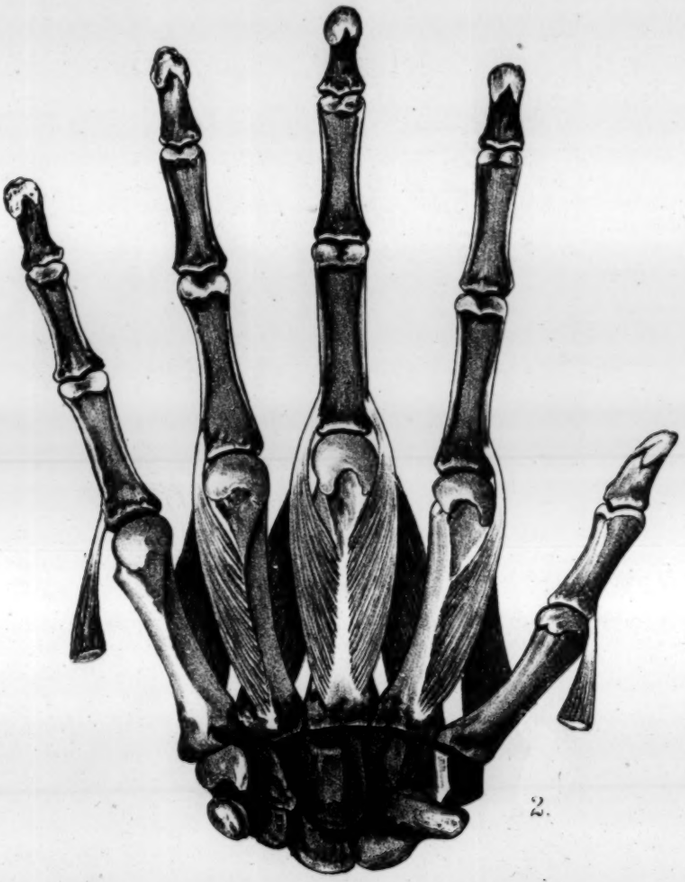
Fig. 2. The *Dorsal* Interossei, *according to current descriptions*, are shown from the Palmar aspect. The Abductor pollicis and Abductor minimi digiti are partly figured.

Fig. 3. The *Palmar* Interossei of current descriptions.

Fig. 4. The series of muscles for which it is proposed to utilise the name *Flexores breves digitorum*. The divided muscles are the Abductor pollicis and Abductor minimi digiti. Part of the Opponens minimi digiti is also shown on the shaft of the 5th metacarpal bone.

Dr Hepburn on the Interosseous Muscles of the Human Hand.

1.



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XV.—*The Temperature Variation of the Magnetic Permeability of Magnetite.*

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(Read February 3rd, 1896.)

CONTENTS.

SECTION	PAGE	SECTION	PAGE
I. Introduction,	567	V. Discussion of Apparent and True Susceptibilities,	572
II. Apparatus,	568	VI. Absolute Values of True Susceptibility,	573
III. Disturbances and their Elimination,	568		
IV. Method of Experimenting and Results,	571		

I. Introduction.

1. *Relation to Magnetic Survey.*—After being engaged for some time, in conjunction with Professor Thorpe, upon the Magnetic Survey of the United Kingdom, Professor A. W. Rücker, F.R.S., put forward his theory of Terrestrial Magnetism.*

In connection with this theory, it was desirable to determine the permeabilities of various rocks, both at ordinary and at high temperatures.

2. The investigation which forms the subject of the present paper is an instalment in this direction. Professor Rücker proposed this undertaking and indicated the plan to be followed. It was then carried out under his supervision at the Royal College of Science, London.

3. *Method.*—The Ballistic Method of measuring the susceptibility was adopted. The specimen of magnetite is placed in the magnetic field produced by a long primary coil in the form of a helix. Round the middle of this is a short secondary coil. Upon the reversal of the current in the primary coil, a transient induced current is sent by the secondary coil through a galvanometer in series with it.

The true effect sought is that due to the introduction of the specimen of magnetite. This depends upon its magnetic susceptibility and its dimensions. The effect at first obtained is one in which the desired result is complicated, and, it may be, masked by other causes. From these it has to be disentangled, as will be explained later.

4. *Arrangements for High Temperatures.*—Since the specimen of magnetite was to be exposed to high temperatures, the coil to receive it was insulated with asbestos paper and wound upon a porcelain tube. The secondary coil was further insulated from the primary by two sheets of mica to obviate the probability of leakage between the two.

* "Relation between Magnetic Permeability of Rocks and Regional Disturbances," Rücker, *Proc. Roy. Soc.*, vol. xlviii., June 19, 1890.

The source of heat was a gas stove. The temperatures were estimated from the consequent E.M.F. of a thermo-electric couple of platinum and osmium-iridium, one of whose junctions was round the specimen of magnetite and the other in a beaker of water. This couple was first calibrated by placing one junction in melting ice, boiling water, and sulphur vapour * respectively, the other junction being meanwhile at ordinary temperatures.

II. Apparatus.

5. *Electrical Connections.*—The electrical connections used are diagrammatically represented in the following figures :—

Fig. 1.—Primary and Secondary Circuits.

Explanation :—

MM, Specimen of magnetite.
P and S, The primary and secondary coils which are heated (by gas stove not shown in the figure).
P′ and S′, Compensating primary and secondary coils to neutralise the effect of P and S when they contain no specimen of rock.
B, Battery of Daniell's cells.
A, Ammeter to indicate the strength of the primary current.
r, Adjustable resistance to keep primary current constant.
K, A Pohl's commutator.
C, Compensating coil.
G, A highly-sensitive low-resistance galvanometer.

Fig. 2.—Thermo-couple and Potentiometer Circuits.

Explanation :—

MM, Specimen of magnetite.
P, The platinum wire of the thermo-electric couple.
O, The osmium-iridium wire of the thermo-electric couple.
HH, The hot junction, formed by tightly twisting together the bifurcated ends of the platinum wire with those of the osmium-iridium wire.
C, The cold junction (see also fig. 3).
G, Highly-sensitive low-resistance galvanometer.
AXB, A potentiometer read to 0·01 cm., about 60 cm. of its length being used.
R, A constant resistance of 300 ohms.
E, A single low-resistance Daniell's cell for producing a suitable potential difference between A and B.

Fig. 3.—Details of Cold Junction.

Explanation :—

BB, Beaker containing—
W, Water.
SS, Stirrer.
TT, Thermometer.
GG, Glass U-tube for insulating the wires.
C, Copper wire to galvanometer.
J, Soldered joint of copper wire to P.
P, The platinum wire which goes to the hot junction.

There is also another glass U-tube, precisely like the one shown, but containing the junction of the other copper wire with the osmium-iridium wire. This second tube is immersed in the same beaker, close beside the other one, so that both are at the same temperature.

III. Disturbances and their Elimination.

6. *Disturbances and their Elimination—Kick due to* S.—The chief disturbances met with in the course of the determination and the manner of treating them are as follows :—

* The arrangement adopted for obtaining the sulphur vapour and the temperature assigned to it were those given by Messrs Callander and Griffiths (*Proc. Roy. Soc.*, vol. xlix. No. 296, page 56, Dec. 18, 1890) in the paper "On a Determination of the Boiling Point of Sulphur and a Method of Standardising Platinum Resistance Thermometers by reference to it."

First. The kick due to the secondary coil S, fig. 1, when no specimen of rock was in the tube.

This kick was balanced at the outset by the other secondary S′. The truth of this balance was afterwards tested throughout the range of temperatures used for the magnetite. A correction curve was then plotted with temperatures for abscissæ, the ordinates representing the residual kicks due to the imperfect balancing of the two secondaries.

7. *Resistance of* S *varies.*—Second. The variation of the resistance in the secondary circuit due to heating P and S.

The kick of the galvanometer needle varies (*ceteris paribus*) inversely as the total resistance, R, of the secondary circuit. Hence, in order to calculate the variation of kick which would have been obtained had R remained constant throughout, it is necessary in each case to multiply the observed kick by the corresponding value of R. This was accordingly done (see Art. 16, vi.). The values of R were determined by a post-office box, the adjustable resistance of which was shunted to give extreme sensitiveness.

8. *Resistance of* P *varies.*—Third. The change of the resistance of the primary coil, due to heating, changed the current passing through it.

This alteration of resistance was compensated by an adjustment of r, fig. 1. Before taking a kick, this resistance was adjusted until the current regained its standard value.

9. *Field at Galvanometer changes on reversal.*—Fourth. The change of the magnetic field at the galvanometer consequent upon the reversal of the current in the primary coils.

This was neutralised by the compensating coil C, fig. 1. Previous to taking a set of readings for the kick, the galvanometer was disconnected from the secondary circuit, and then this coil was adjusted until no deflection of the galvanometer needle was produced by the reversal of the current in the primary coils.

10. *Leakage.*—Fifth. There might be a leakage between either primary coil and its secondary.

This was, therefore, investigated as follows:—The galvanometer being in series with the secondary coils, it was observed what permanent deflection occurred upon reversal of the primary current. The deflection thus obtained at the beginning of the determination was less than two small scale divisions, and at the close less than one such division, the current in the secondary due to leakage in the two cases being respectively of the order $\frac{1}{30,000,000}$th and $\frac{1}{60,000,000}$th of the primary current in use. A small correction was applied to the kicks for this leakage (see Art. 16, iii. and iv.).

11. *Sensibility might vary.*—Sixth. Any appreciable variation of the sensibility of the galvanometer would invalidate a comparison of the kicks obtained at different times.

To prevent, as far as possible, this irregularity, the whole determination was conducted in a separate room, specially free from magnetic disturbances. Further, the

galvanometer remained in the same place throughout, and with its controlling magnet at a definite height. The diurnal variations of the earth's magnetic field were considered negligible.

12. *Thermo-electric Effects.*—Seventh. When the magnetite was strongly heated considerable trouble was at first experienced owing to slight fluctuations in the temperature of the secondary coil encircling the specimen. Indeed, the variations thus set up in the thermo-electric current flowing round the secondary circuit often caused an irregular movement of the galvanometer needle greater than the kicks to be obtained by induction.

Advantage was then taken of the fact that, although the time-integral of the thermo-current often equalled or exceeded the time-integral of the induced current, yet the E.M.F. of the induced current was much the greater of the two. Hence, any method of exposing the galvanometer to this double effect for a space of time so short as to be at all comparable with the duration of the induction phenomena would practically eliminate the disturbance due to the thermo-current. To accomplish this, some automatic double-contact maker was needed. Professor C. V. Boys, F.R.S., then suggested the use of a pendulum working on a geometrical hinge, and carrying two platinum points passing through troughs containing mercury. The use of this pendulum, however, showed that the high temperatures at first contemplated would not be required, for at about 600° C. the permeability of the magnetite was found to have already become unity. It was, therefore, not necessary to explore the permeability of the specimen beyond this point. Moreover, for the comparatively moderate temperatures needed it was possible so far to moderate the variations in the thermo-currents as to make the use of the Pohl's reversing commutator quite admissible. This was effected by covering the coils P and S, fig. 1, with asbestos wool and cloths and carefully excluding all draughts of air. The reversing commutator was accordingly used throughout the observations in preference to the pendulum, which, in the simple form rigged up, only made or broke the current.

13. *Magnetite unequally heated.*—Eighth. Errors might arise through non-uniformity of temperature throughout the specimen of magnetite.

These were to a great extent obviated by turning on the gas of the stove to a certain amount, and leaving the coils and specimen exposed to this constant flame for some time. The temperature was read at intervals by the thermo-couple and potentiometer; and only when further rise of temperature had almost ceased was a set of readings for the kick taken.

14. *Magnetite crumbles on heating.*—Of the original specimen of magnetite about half crumbled away on the first heating.

As it is difficult to get large pieces of magnetite which can bear exposure to high temperatures, the remnant from the first piece was next tried. This small piece bore, without any sign of damage, repeated heatings, and was employed throughout the determination for the kick at various temperatures.

IV. Method of Experimenting and Results.

15. *Practice of the Method.*—The *modus operandi* of the investigation is therefore as follows:—

Suppose the kick at a temperature of about 300° C. is desired. The gas stove is arranged to give the flame judged most suitable. The temperature is read at intervals. When the required temperature is approached, if the rise of temperature is still rapid, the stove is lowered until the temperature very slowly rises towards the 300° C. After the temperature has been fairly steady for some time, the reading of the potentiometer and the temperature of the cold junction are recorded. The compensating coil C, fig. 1, is set. The primary current is read and adjusted to its standard value. The primary current is reversed, by *pulling* the commutator bar, and the kick observed and registered. The current is again read and adjusted, if necessary, to its standard value. The primary current is now reversed by *pushing* the commutator bar, and the kick again noted. The mean of these two kicks is taken. The two opposite reversals of the primary current are repeated several times, and the mean of the various means is used as the true value for the kick at the temperature in question. At the close of the observations for the kick the potentiometer and cold junction are read a second time, and the adjustment of the compensating coil C, fig. 1, again verified.

16. *Results.*—The results obtained are exhibited graphically in the annexed curves, namely:—

(i.) Calibration of thermo-electric couple.

(ii.) Kicks obtained at the various temperatures.

The apparently anomalous character of this curve in the neighbourhood of 325° C. was confirmed by a second investigation of this particular region. It is therefore allowed to stand as originally plotted.

(iii.) Corrections to kicks, owing to

(α) Imperfect balancing of coils themselves, and to

(β) Leakage between primaries and their secondaries.

(iv.) Corrected kicks, being the resultant of (ii.) and (iii.). The ordinates of (ii.) are, of course, the algebraic sums of the corresponding ordinates of (iii.) and (iv.).

(v.) Resistances of secondary circuit for various temperatures of hot junction HH, fig. 2.

(vi.) Curve whose ordinates are proportional to the apparent susceptibility, κ', of the magnetite specimen throughout the observed range of temperatures. The ordinates of this curve are the products of the corresponding ordinates of curves (iv.) and (v.).

V. Discussion of Apparent and True Susceptibilities.

17. *Susceptibility: Apparent and Real Values.*—This curve does not, however, give the variation in the true susceptibility of the specimen, as might be at first supposed. On the contrary, it gives only a first approximation to the susceptibility, because, hitherto, the reaction of the specimen on the impressed field has not been considered. The ordinates of (vi.) would have been proportional to the true values of the susceptibility if the *actual magnetic field* H, *within the specimen*, had been maintained constant throughout. Instead, however, of this being the case, the *impressed magnetic field*, H′, has been constant. Now we have* (for an ellipsoid)

$$H = H' - NI,$$

where N is a constant depending on the relation of the length of the ellipsoid and its transverse dimensions, and I is the intensity of magnetisation of the specimen. The above equation may be written

$$H = H' - N\kappa H,$$

where κ is the magnetic susceptibility, hence we get

$$H(1+N\kappa) = H' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Again, since the two secondary coils balance each other, we may write

$$\kappa H = (\text{induction effect}) \times (\text{a constant}) = \kappa' H' \quad . \quad . \quad . \quad . \quad (2)$$

κ' being the first approximation to the susceptibility alluded to (Art. 16, vi.). Hence H′ having been constant, we have κ' proportional to the induction effects. Now, to get κ in terms of κ' and N, we must eliminate H and H′ between (1) and (2). It will be convenient to express the relation thus obtained in several ways, viz. :—

$$\frac{\kappa}{1+N\kappa} = \kappa' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$N\kappa\kappa' - \kappa + \kappa' = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\kappa = \frac{\kappa'}{1-N\kappa'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\left(\kappa + \frac{1}{N}\right)\left(\kappa - \frac{1}{N}\right) = -\frac{1}{N^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

18. If the variables κ and κ' be regarded as mutually rectangular coordinates, the above relation between them represents a rectangular hyperbola whose asymptotes may be written

$$\left(x + \frac{1}{N}\right)\left(y - \frac{1}{N}\right) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

* *Magnetic Induction in Iron and other Metals*, by J. A. Ewing, F.R.S., pp. 24, 25.

Thus the curve may be plotted exhibiting graphically the relation between κ and κ'. The two branches of the curve are shown in figure 4.

Now it is clear, from the physical conditions of the case, that κ and κ' are of the same sign, and, from (3), that when κ is infinite κ' becomes $\frac{1}{N}$. Hence we see that if in fig. 4, κ be measured along OK and κ' along OK', it is only the part OPQ of the curve which expresses the actual relation between κ and κ'.

19. *κ' and N required.*—But before this curve can be of any service, one must know the relative scale of the curve (vi.) whose ordinates are proportional to the values of κ' for the specimen, and the curve in fig. 4 which exhibits the relation between κ and κ' in terms of the constant N. It thus became necessary to determine κ' at some one temperature and to estimate N. An independent absolute measurement of κ at ordinary temperatures with a larger piece of magnetite seemed desirable also, both for its own sake and as a stepping-stone to the foregoing. These ends were accomplished by the following methods—

VI. Absolute Values of True Susceptibility.

20. *Absolute Value of κ.*—For determining the absolute value of κ, for the longer specimen of magnetite, the electrical connections shown in fig. 1 were again employed. The specimen now used was still so short that its reaction on the original magnetic field could not be neglected. It was therefore matched, magnetically, by a preparation containing finely-divided iron and occupying exactly the same volume and position in the coils P and S, fig. 1, as did the specimen of rock. A cylinder of the same composition and about 100 diameters long was then used. For the very slight effect of its ends a correction was applied on the supposition that it was equivalent to an ellipsoid. In matching the mixtures against the actual specimen of magnetite, the secondaries S and S′ were arranged so as to exactly neutralise one another's effects. In getting the value of κ from the long cylinder of the mixture, this balance was disturbed. The cylinder was first introduced in S and readings for the kick taken, then the cylinder was placed in S′ and readings for the kick again taken. Hence two equations are obtained. Between these two equations the entire constant for the galvanometer and the total resistance of the secondary circuit can be at once eliminated and κ obtained in terms of known quantities.

21. *Theory*—Thus, referring to fig. 1,

Let p denote the number of turns per cm. of length in the primary coils P and P′ (they were the same).

a and a' the cross-sectional areas of P and P′.

s and s' the total number of turns in the secondaries S and S′, after the balance has been disturbed.

A the cross-sectional area of the long cylinder of mixture.

C the primary current in electro-magnetic units.

H′ the impressed magnetic field $=\gamma(4\pi pC)$, ... (1)

γ being a factor less than unity to correct for the effect of the ends of P and P′.

H the actual field within the composition * $=H'-NI=H'-N\kappa H$, so that

$$H=\frac{H'}{1+N\kappa}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where κ is the magnetic susceptibility of the substance, and N a constant depending upon the dimensions of the magnetic body introduced into the field.

Γ the entire constant of the galvanometer, *i.e.*:—

$$=\frac{H}{G}\cdot\frac{T}{\pi}\left(1+\frac{\lambda}{2}\right),$$

H being the magnetic field at galvanometer when no current flows through it; G the field produced at galvanometer needle by absolute unit current passing through galvanometer; T the complete period of an oscillation of galvanometer needle; λ its logarithmic decrement.

R the total resistance of the secondary circuit.

Now, *first*, put the long cylinder of composition in P. Then the total magnetic flux through S and S′ is given by

$$Hs(a+4\pi\kappa A)-H'(a's')\text{ or}$$

$$\frac{H'}{1+N\kappa}\Big[s(a+4\pi\kappa A)-a's'(1+N\kappa)\Big] \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

S′ being arranged so as to oppose S.

Hence the quantity of electricity passing through the galvanometer on reversal of primary current is $\frac{2}{R}$ times the expression (3). Thus, if the resulting kick is α counted positive if in the direction due to S, we have

$$\frac{2}{R}\cdot\frac{H}{1+N\kappa}\Big[s(a+4\pi\kappa A)-a's'(1+N\kappa)\Big]=\Gamma\sin\frac{\alpha}{2} \quad . \quad . \quad . \quad . \quad (4)$$

Similarly when, *second*, the long cylinder of composition is put in P′, and the kick β obtained counted positive if in the direction due to S, we have

$$\frac{2}{R}\cdot\frac{H'}{1+N\kappa}\Big[as(1+N\kappa)-s'(a'+4\pi\kappa A)\Big]=\Gamma\sin\frac{\beta}{2} \quad . \quad . \quad . \quad . \quad (5)$$

Hence, neglecting the differences between tangents, arcs, and sines of small angles, we obtain from (4) and (5)

$$\{s(a+4\pi\kappa A)-a's'(1+N\kappa)\}\beta=\{as(1+N\kappa)-s'(a'+4\pi\kappa A)\}\alpha$$

or

$$\kappa=\frac{(\alpha-\beta)(as-a's')}{4\pi A(as'+\beta s)-N(\alpha as+\beta a's')} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

* *Magnetic Induction in Iron and other Metals*, by J. A. Ewing, F.R.S., pp. 24, 25.

22. *Experiment.*—In the practice of the foregoing method a composition of levigated iron, beeswax, and resin was first tried. This, however, gave trouble in two ways. First, it was almost impossible to secure homogeneity, the iron settling immediately on the cessation of stirring and before the wax and resin had solidified. Secondly, on attempting to make a long cylinder of the mixture by pouring it into a glass tube, it was found that the contraction on solidification was such that the composition shrank from the sides of the tube, thus giving rise to an irregularly shaped body quite useless for the end in view.

A composition of levigated iron and plaster of Paris, well mixed with pestle and mortar in the dry state and so used, was then tried, and it seemed quite satisfactory.

To imitate correctly the size and shape of the piece of magnetite, the mixture was rammed into a boat made by wrapping copper foil round the magnetite specimen, taking it off and soldering up the edges. The long cylinder was obtained by ramming the same mixture into a glass tube about 100 diameters long. Before taking a pair of readings for the kick with this composition, the primary current was rapidly reversed a number of times; as, without this precaution, the induction was found to diminish materially if kicks were taken at the ordinary intervals of reading. A few reversals, however, at once restored the mixture to its standard magnetic condition.

23. The secondaries S and S′ being balanced, the kicks obtained were as shown in the table.

Magnetic Substance.			Galvanometer Kick.
Specimen of magnetite, 1·3 cm. square, 4·9 cm. long.			202 scale divisions.
Mixture.	Iron (gm.).	Plaster of Paris (gm.).	
No. 1	25	5	182
2	30	5	205 } Mean of these two = 202·25.
3	28·5	5	199·5 }

The constants of the apparatus, using symbols as explained in Art. 21, were as follows:—

$p = 7{\cdot}9$ no. per cm.

$a = 5{\cdot}62$ sq. cm. $a' = 5{\cdot}41$ sq. cm.

$s = 159$. $s' = 136$.

$A = 0{\cdot}36$ sq. cm.

$C = {\cdot}0485$ c.g.s. units. Thus $H' = \gamma(4\pi pC) = \gamma \times 4{\cdot}82$ c.g.s. units.

$N = {\cdot}005$.*

$R = 3 \times 10^9$ c.g.s. units.

* Ewing's *Magnetic Induction in Iron and other Metals*, p. 32; Maxwell's *Electricity and Magnetism*, 3rd edition, vol. ii. pp. 69, 70.

Results.—The kicks obtained with mixtures 2 and 3, and the deduced values of κ for them, are shown in the following table :—

No. of Mixture.	Scale Divisions for α.	Scale Divisions for β.	κ
2	+118·5	−56·2	0·86
3	+113	−51·2	0·78

Hence the value of κ for the specimen of magnetite used is

$$0{\cdot}82 \text{ nearly} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

24. *Other Results.*—Having κ we can get Γ from either (4) or (5). Putting in (4) $\kappa = 0{\cdot}86$ and $\alpha = 118{\cdot}5$, we obtain

$$\Gamma = (0{\cdot}000121)\gamma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

From Γ we can determine κ'. Thus in the case where, with the secondaries balanced, a kick of 202 was obtained with this specimen of magnetite, we have the equation

$$\frac{2}{R}(H'\kappa' 4\pi As) = \Gamma \sin\left(\frac{\text{arc tan } \frac{202}{1440}}{4}\right)$$

1440 being the distance in scale divisions of the needle from the scale.

And on substituting here the value of Γ already quoted, we obtain

$$\kappa' = 0{\cdot}39 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Again from equation (4), Art. 17, we have

$$N = \frac{\kappa - \kappa'}{\kappa\kappa'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Thus for the piece of magnetite in question

$$N = \frac{0{\cdot}82 - 0{\cdot}39}{0{\cdot}82 \times 0{\cdot}39} = 1{\cdot}34 \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

This piece has a length equal to 3·36 times its equivalent diameter (*i.e.*, the diameter of a cylinder of equal cross-sectional area). Now applying the formula *

$$N = 4\pi\left(\frac{1}{e^2} - 1\right)\left(\frac{1}{2e}\log_\epsilon \frac{1+e}{1-e} - 1\right) \quad . \quad . \quad . \quad . \quad . \quad (12)$$

* MAXWELL's *Electricity and Magnetism*, 3rd edition, vol. ii. p. 69.

to an ellipsoid three diameters long, we obtain the theoretical value

$$N = 1{\cdot}2165 .$$

Hence we see that N appears to have a rather larger value in this case than theory would predict for a similar ellipsoid.

Employing, again, the value of Γ as before, we find that, for the fragment of magnetite used for the temperature variation, the value of κ' for ordinary temperatures is given by

$$\kappa' = 0{\cdot}151 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

This fragment was part of a prism 1·3 cm. square, with one end at right angles to its long edges, whose lengths were respectively 1·9, 2·2, 3·2, and 2·8 cm. long, and is represented in figure 5.

Its mean length is 1·76 times its equivalent diameter (*i.e.*, the diameter of a cylinder of equal cross-sectional area). Now for an ellipsoid of two diameters long we get, from equation (12), $N = 2{\cdot}13$. By analogy from the case of the larger piece, N might be

Table showing Values of κ and μ for Various Temperatures.

Temperatures in Degrees Centigrade.	Ordinates of Curve (vi.).	κ' for Fragment of Magnetite.	$\kappa = \frac{\kappa'}{1-2\kappa'} =$ Ordinates of (vii.).	$\mu = 1+4\pi\kappa =$ Ordinates of (viii.).
20° C.	233	0·151	0·216	3·71
50	243	·158	·231	3·90
75	249	·161	·237	3·97
100	252	·163	·242	4·04
125	256	·166	·249	4·12
150	260	·169	·255	4·20
175	265	·172	·262	4·29
200	270	·175	·269	4·37
225	279	·181	·283	4·55
250	288	·187	·299	4·75
275	296	·192	·312	4·91
300	305	·198	·328	5·12
325	314	·203	·342	5·29
350	282	·183	·289	4·63
375	272	·176	·272	4·41
400	267	·173	·265	4·32
425	265	·172	·262	4·29
450	263	·171	·260	4·26
475	257	·167	·251	4·15
500	246	·159	·233	3·92
525	181	·117	·153	2·92
540	47	·030	·032	1·40
557	0	0·000	0·000	1·00

greater than this, say 2·35. But to avoid over-estimating the correction to be applied by this factor, let us put, for the small piece of magnetite used in the temperature variation, $N = 2$.

25. *Final Results, κ and μ.*—Then from curve (vi.) and the value of κ' at ordinary temperatures we have the values of κ' for all the temperatures. Hence, using the relation (5), Art. 17,

$$\kappa = \frac{\kappa'}{1 - N\kappa'},$$

we get the values of κ for the various temperatures. Finally, since μ, the magnetic permeability, $= 1 + 4\pi\kappa$, we can calculate μ as required. These results are exhibited in the table on page 577, and in the curves (vii.) and (viii.).

26. *Fields used.—Note.* The impressed field H′ was the same throughout, namely, 4·82 c.g.s. units (nearly).* The true fields H within the specimens would be—

(i.) For the piece of magnetite 4·9 cm. long used for the absolute value of κ,

$$H = \frac{H'}{1 + N\kappa} = \frac{4{\cdot}82}{1 + (1{\cdot}34 \times {\cdot}82)} = 2{\cdot}3 \text{ c.g.s. units (nearly).*}$$

(ii.) For the fragment of magnetite used for the temperature variation of μ, at 20° C.,

$$H = \frac{H'}{1 + N\kappa} = \frac{4{\cdot}82}{1 + (2 \times {\cdot}216)} = 3{\cdot}4 \text{ c.g.s. units (nearly).*}$$

(iii.) For the latter piece of magnetite at 325° C.,

$$H = \frac{4{\cdot}82}{1 + (2 \times {\cdot}342)} = 2{\cdot}9 \text{ c.g.s. units (nearly).*}$$

In conclusion, I have pleasure in expressing my thanks to Professor Rücker, F.R.S., for suggesting this work to me; and to Mr W. Williams, B.Sc., for winding the two primary and two secondary coils which were used throughout these experiments.

* Strictly speaking, all these fields are affected by the factor γ, (see Art. 21, i.). But in all probability this factor is practically unity.

FIG. 1.

PRIMARY AND SECONDARY CIRCUITS.

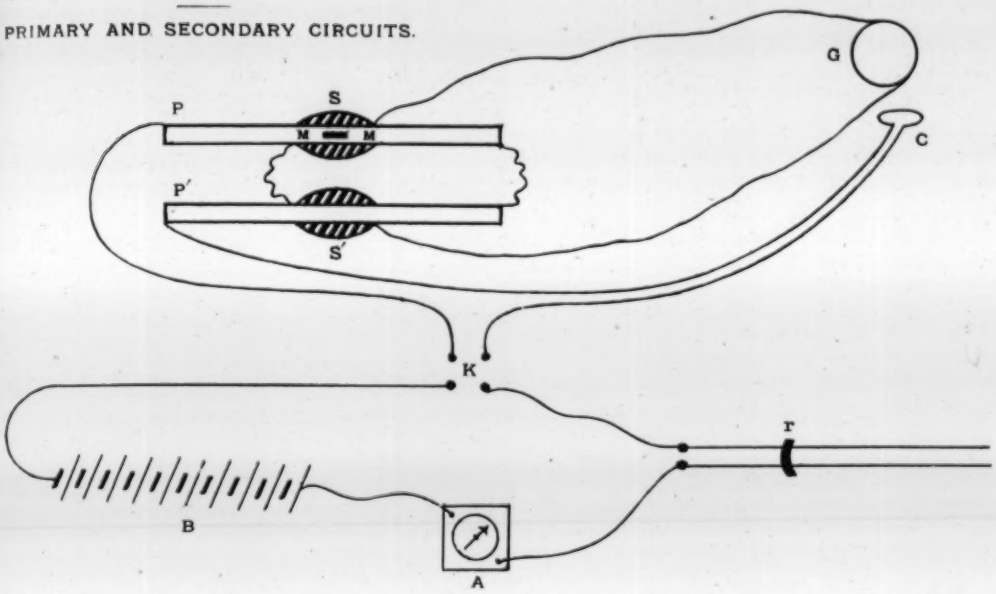


FIG. 5.

FRAGMENT OF MAGNETITE.

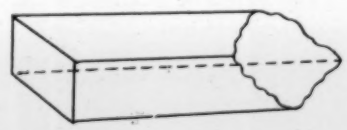


FIG. 2.

THERMO-COUPLE AND POTENTIOMETER CIRCUITS.

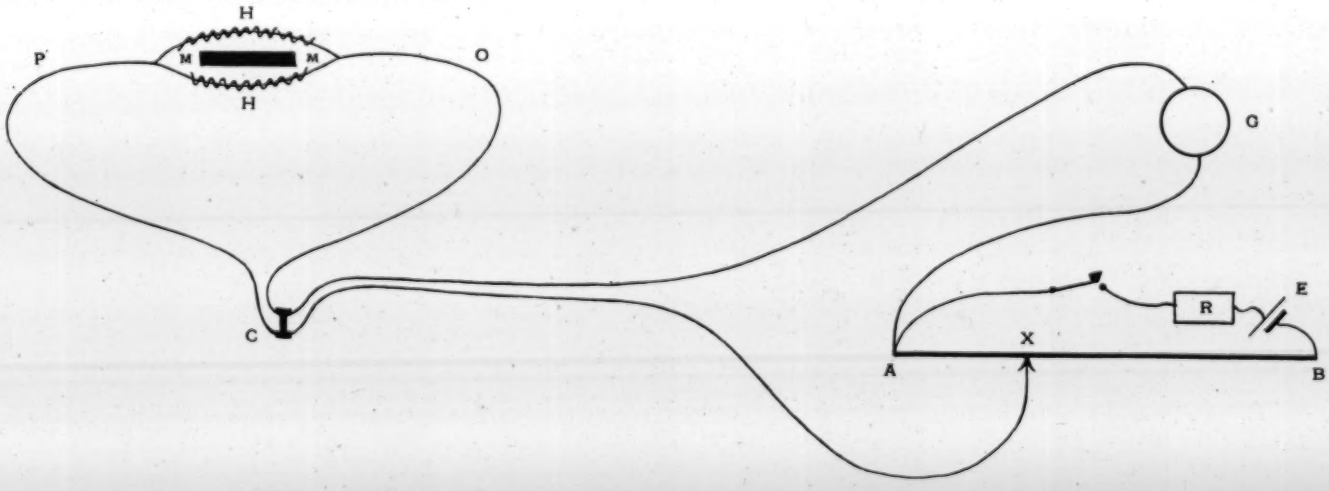


FIG. 4.

ELATION BETWEEN

$\mathcal{K}$ AND K

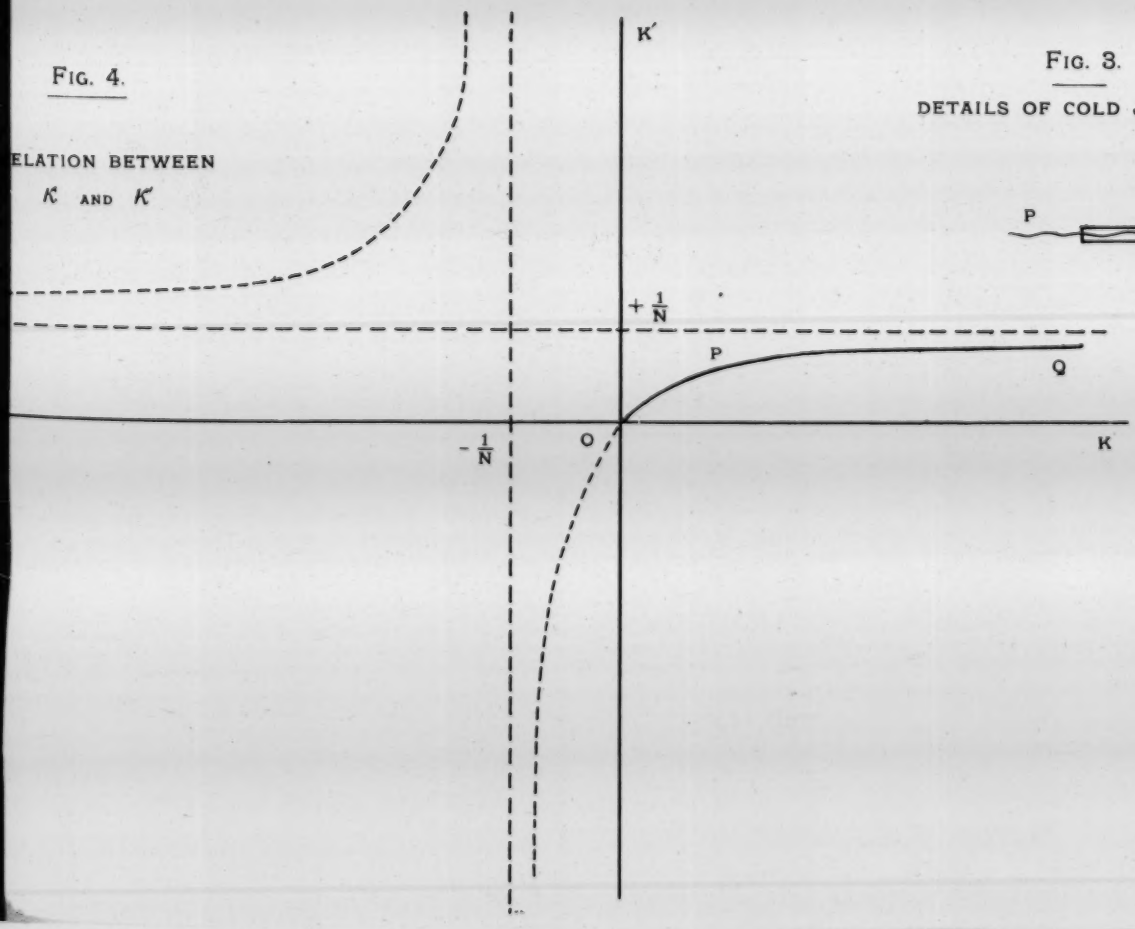
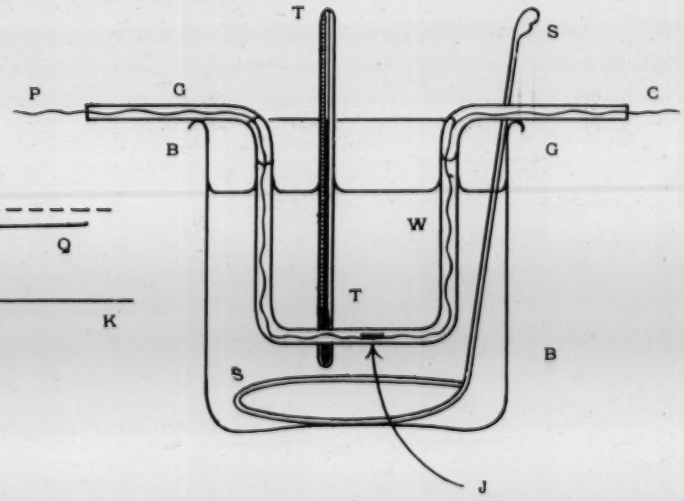


FIG. 3.

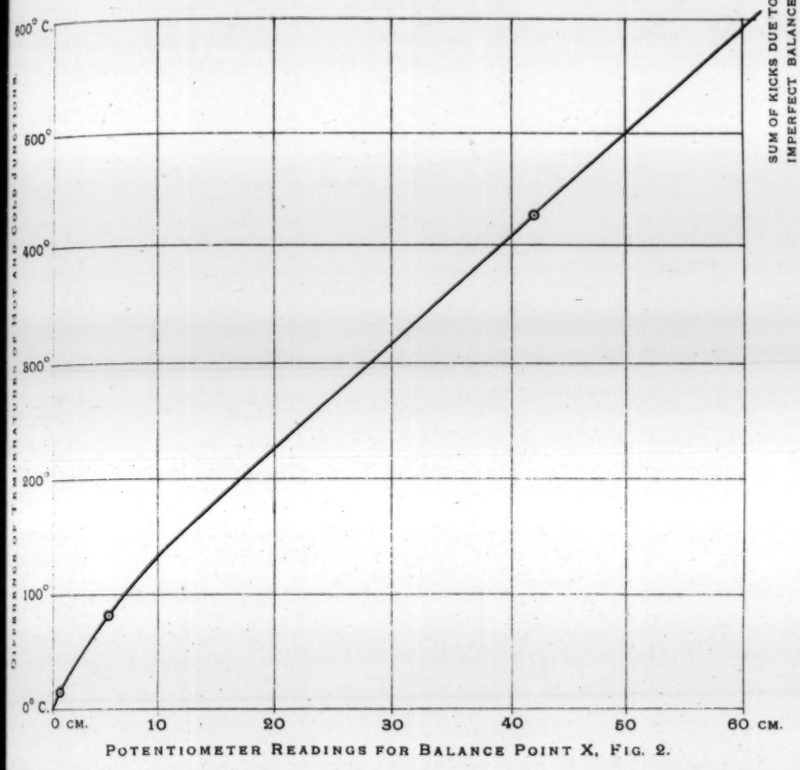
DETAILS OF COLD JUNCTION.



Dr. Barton on the Temperature Variation of the Magnetic Permeability of Magnet

Curve (I).

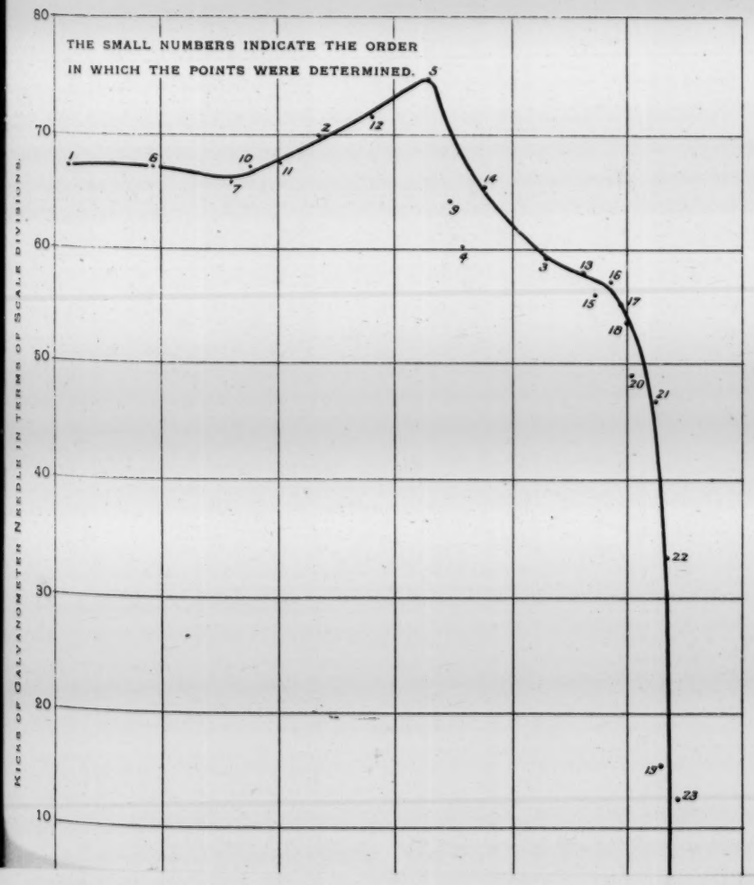
Calibration of thermo-electric couple.



Potentiometer Readings for Balance Point X, Fig. 2.

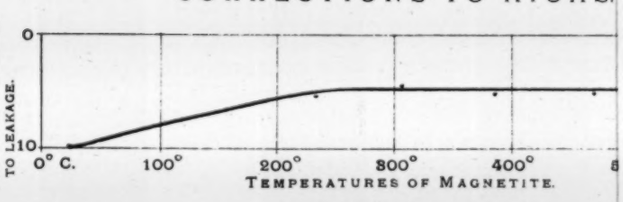
Curve (II).

Observed kicks.



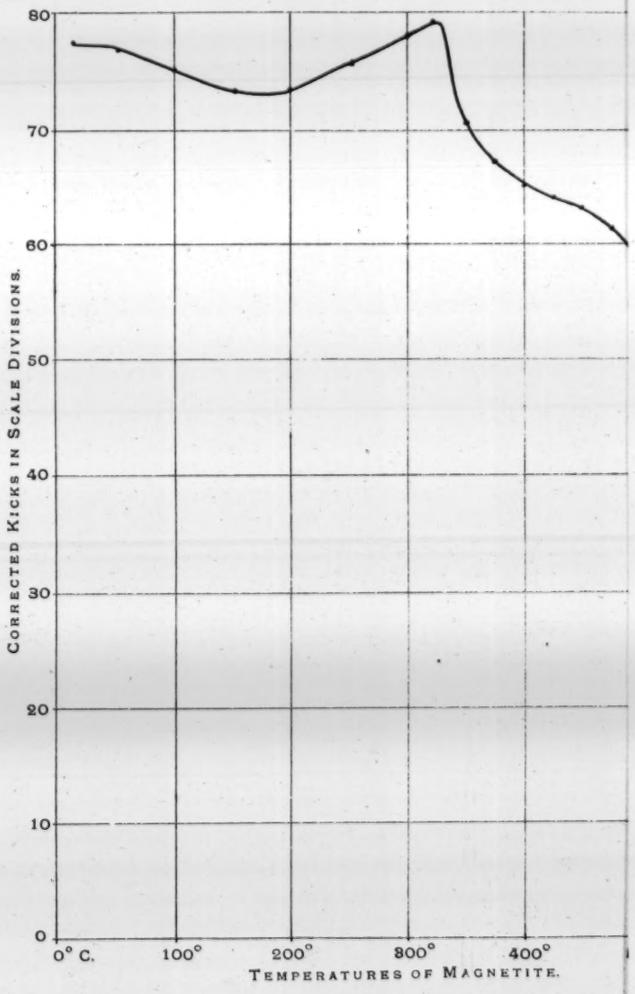
Curve (III).

Corrections to kicks.



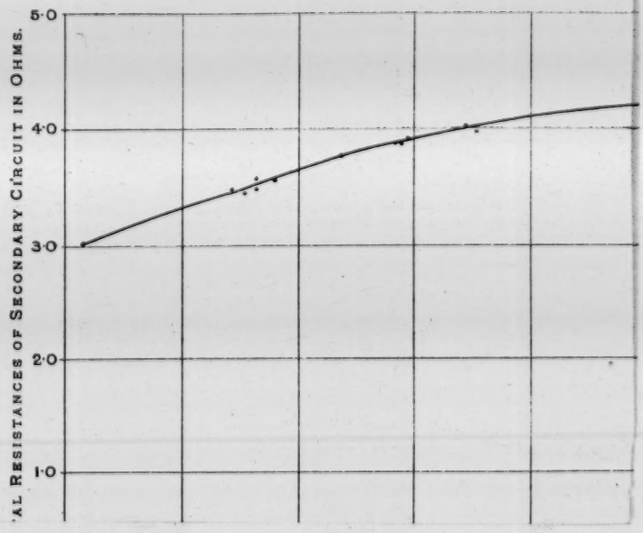
Curve (IV).

Corrected kicks.



Curve (V).

Resistance of secondary circ

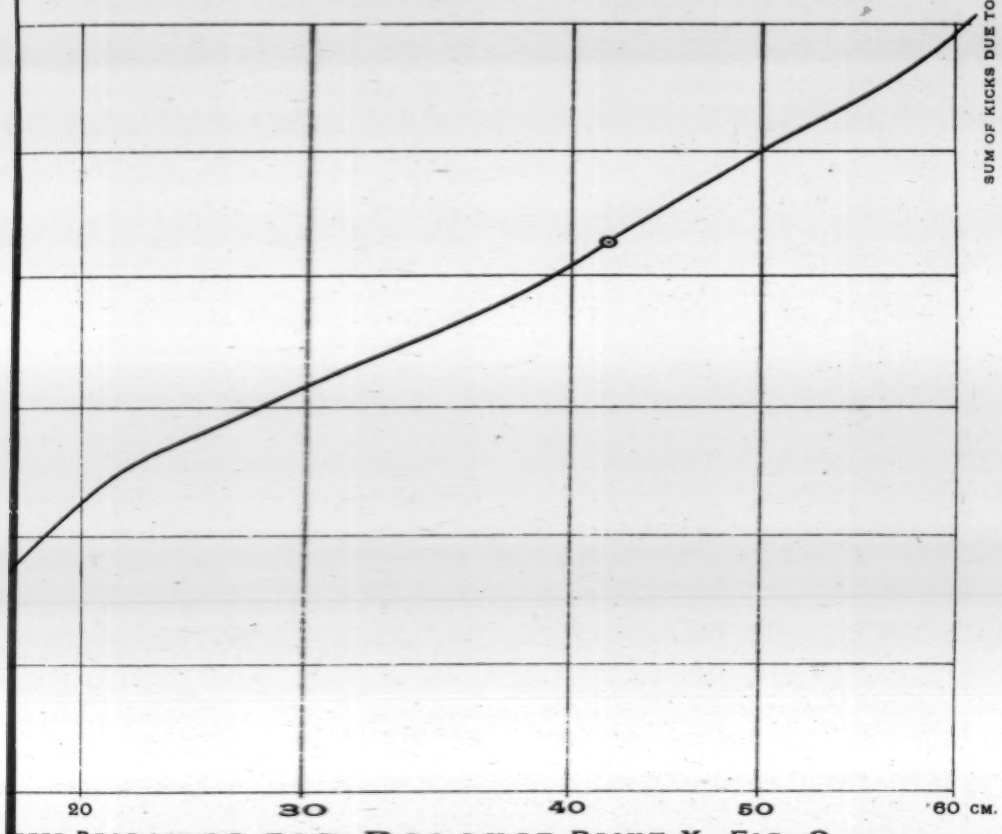


ON THE TEMPERATURE VARIATION OF THE MAGNETIC PERMEABILITY OF MAGNETITE.

PLATE II.

CURVE (I).

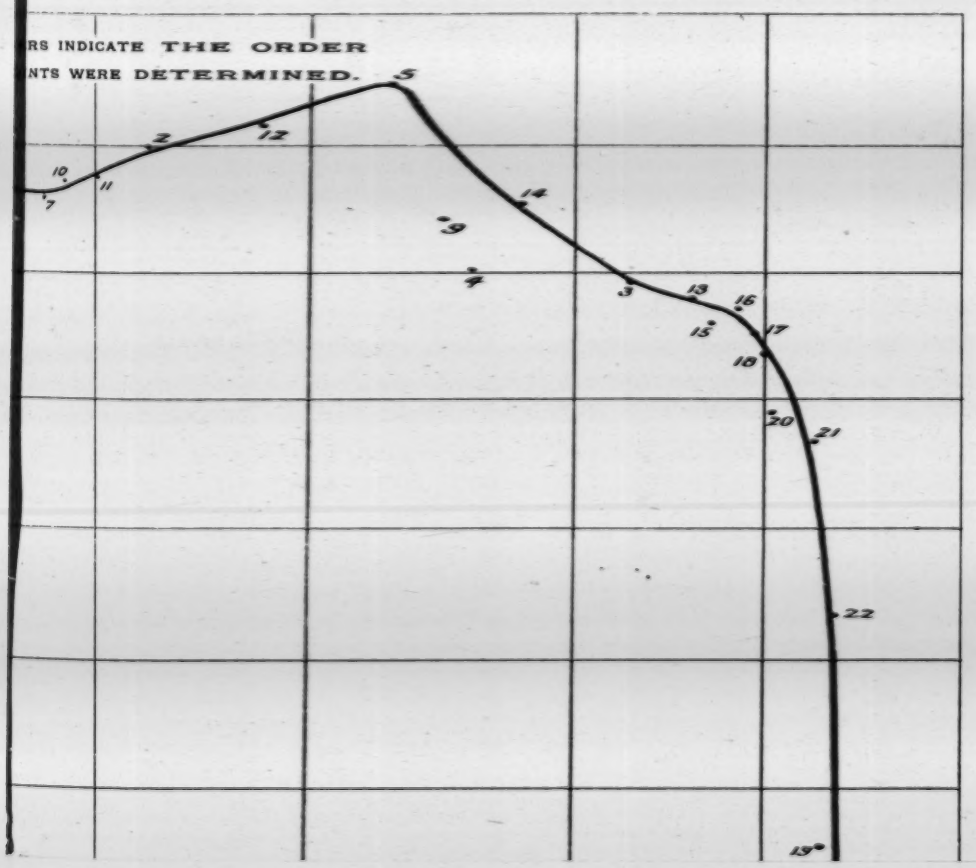
ON OF THERMO-ELECTRIC COUPLE.



ETER READINGS FOR BALANCE POINT X, FIG. 2.

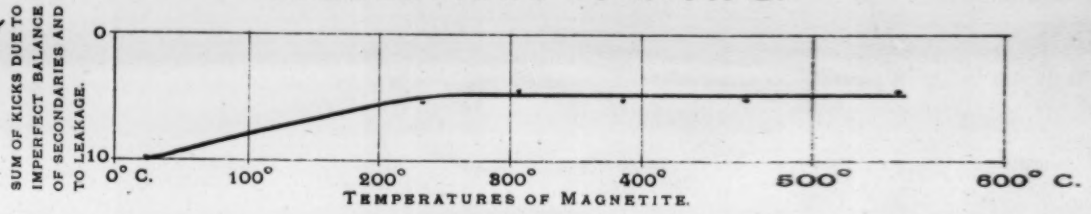
CURVE (II).

OBSERVED KICKS.



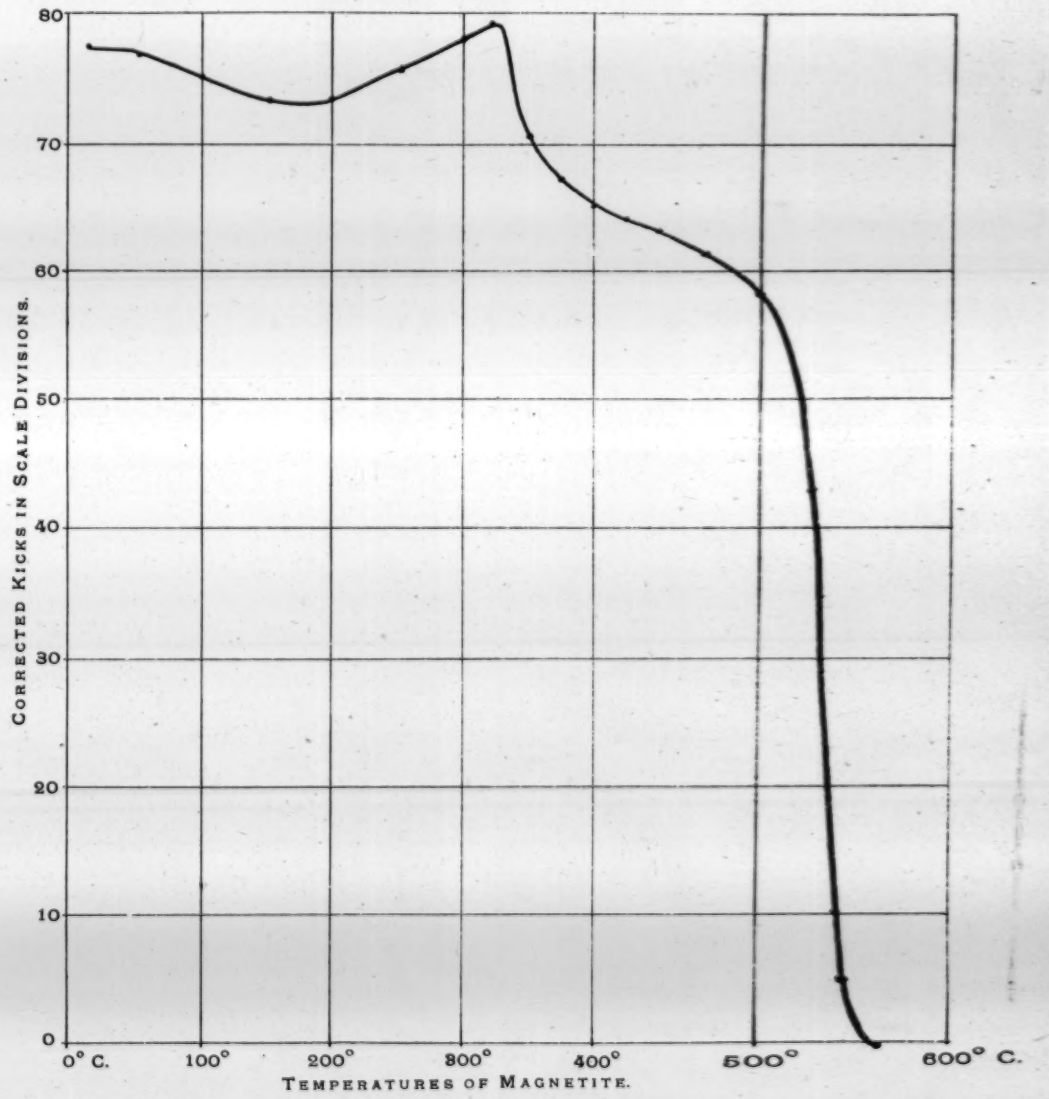
CURVE (III).

CORRECTIONS TO KICKS.



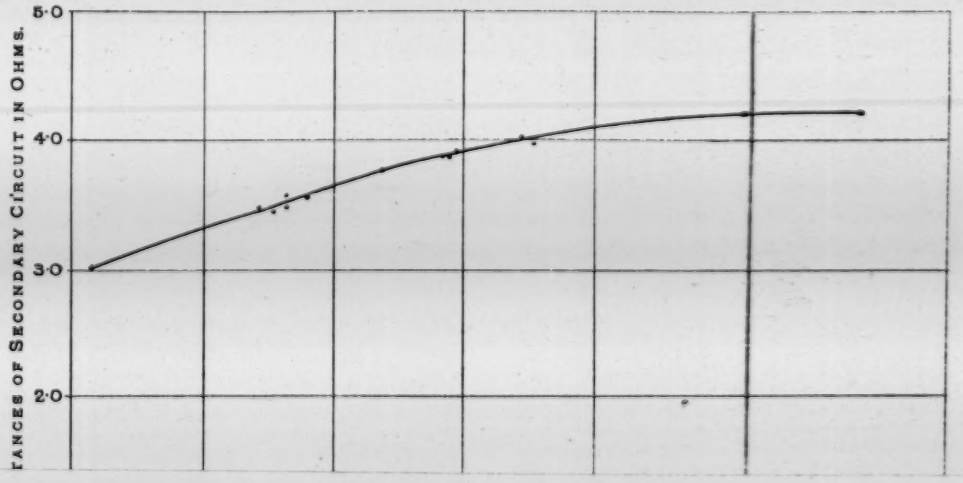
CURVE (IV).

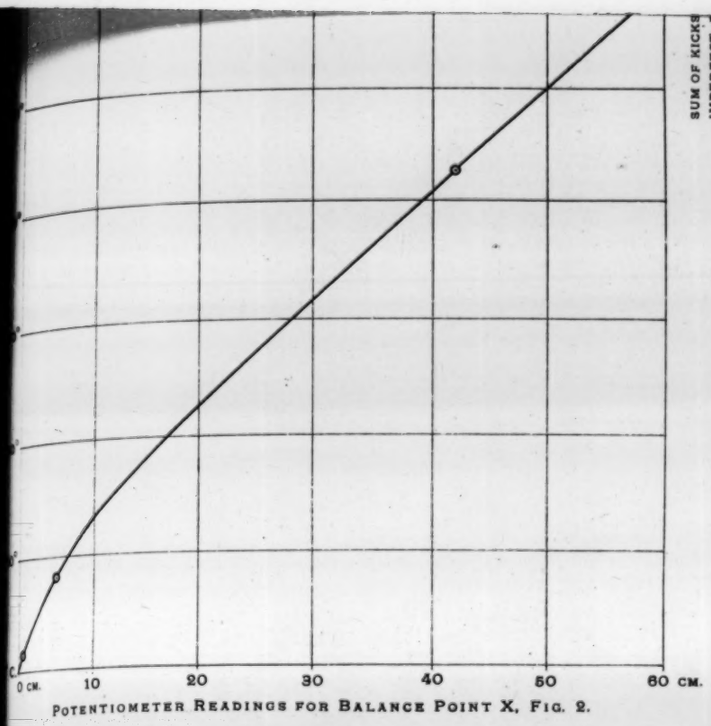
CORRECTED KICKS.



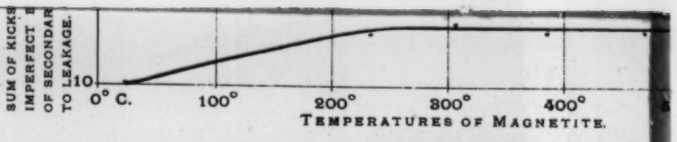
CURVE (V).

RESISTANCE OF SECONDARY CIRCUIT.



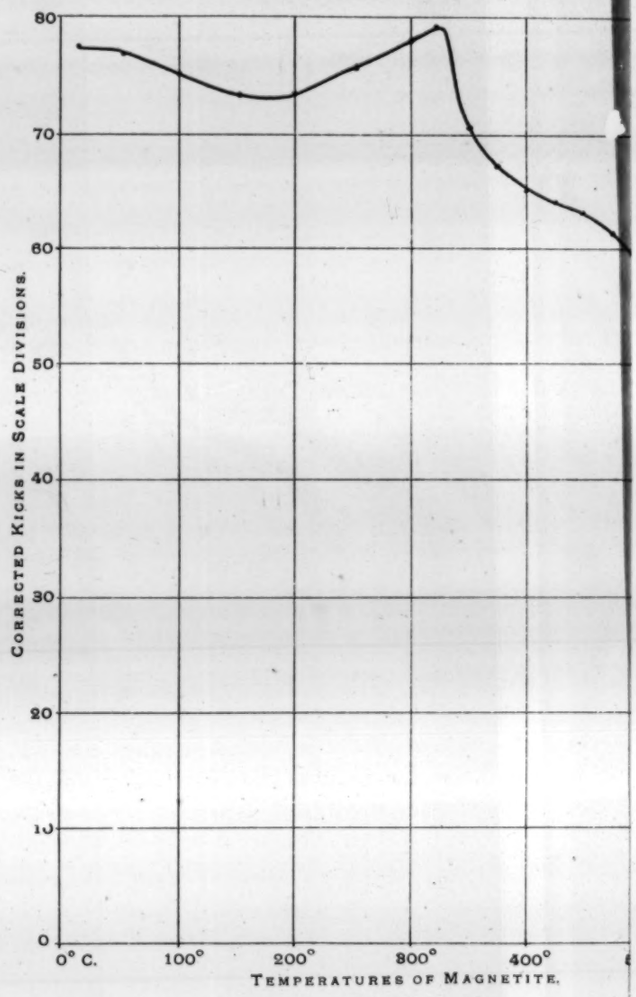


POTENTIOMETER READINGS FOR BALANCE POINT X, FIG. 2.



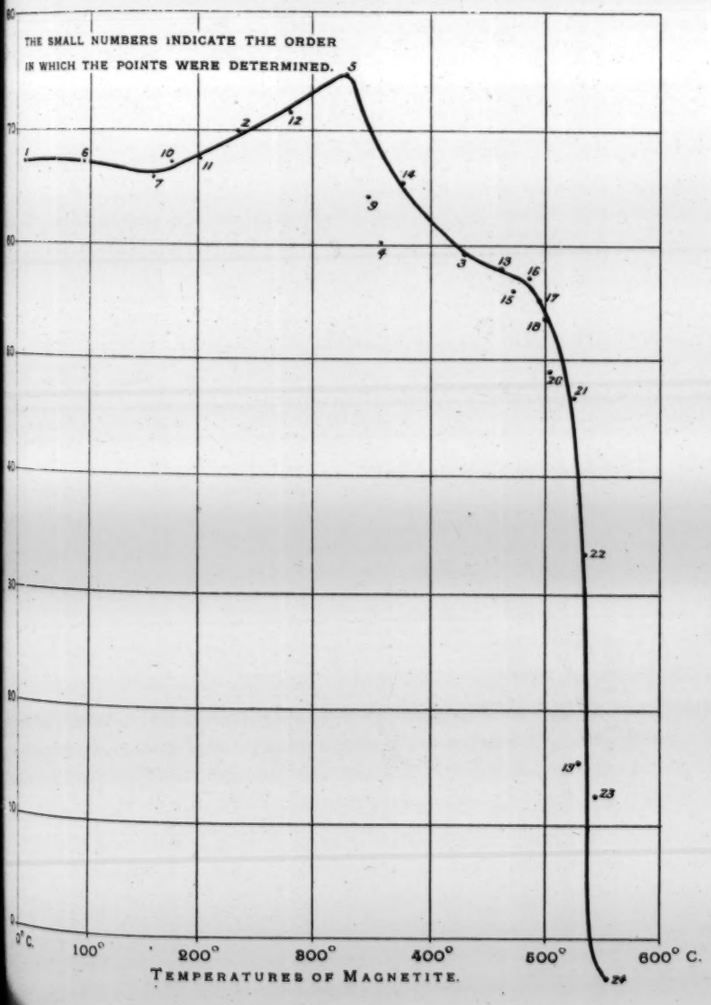
CURVE (IV).

CORRECTED KICKS.



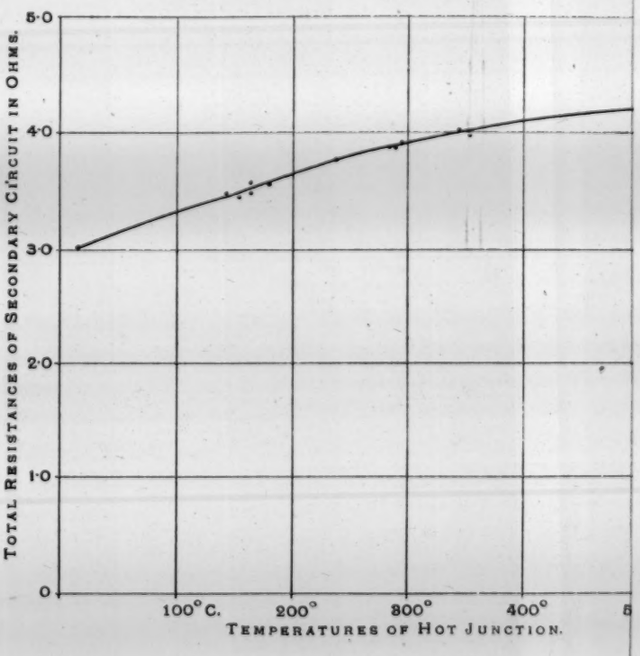
CURVE (II).

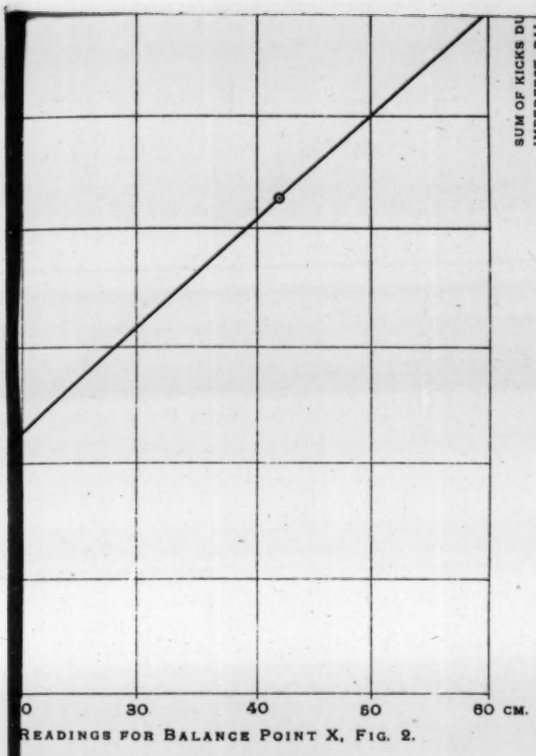
OBSERVED KICKS.



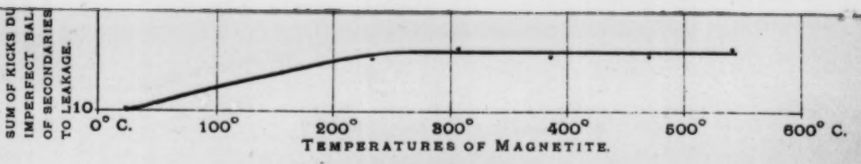
CURVE (V).

RESISTANCE OF SECONDARY CIRCU



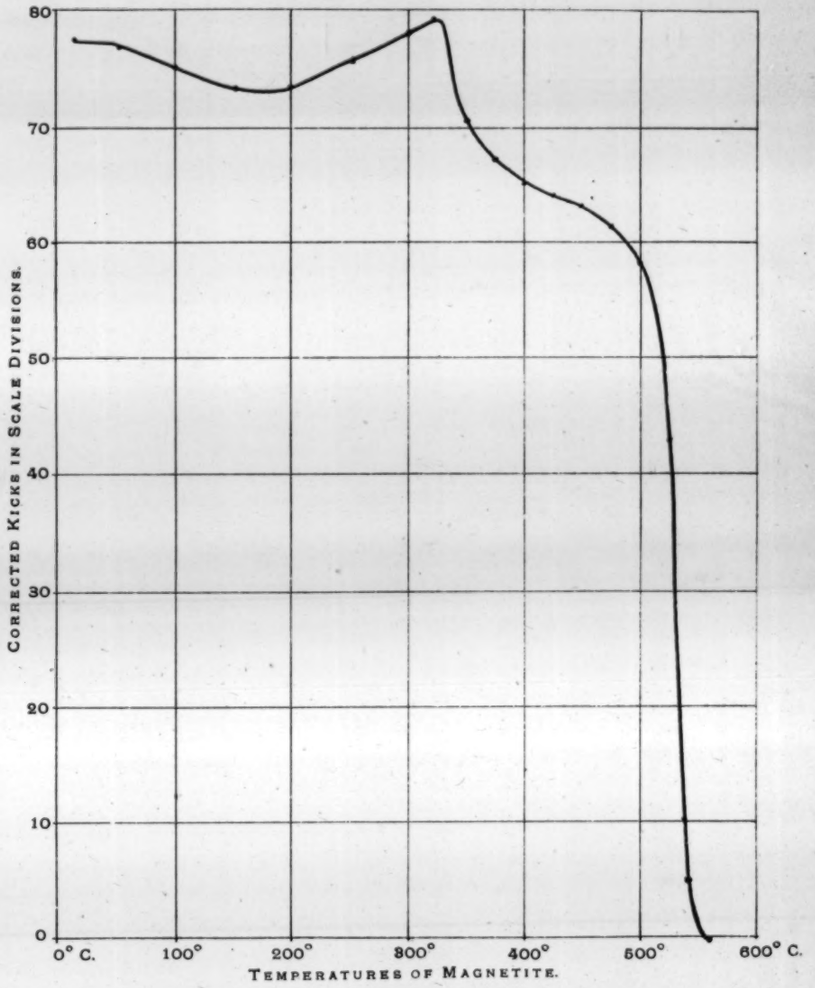


Readings for Balance Point X, Fig. 2.



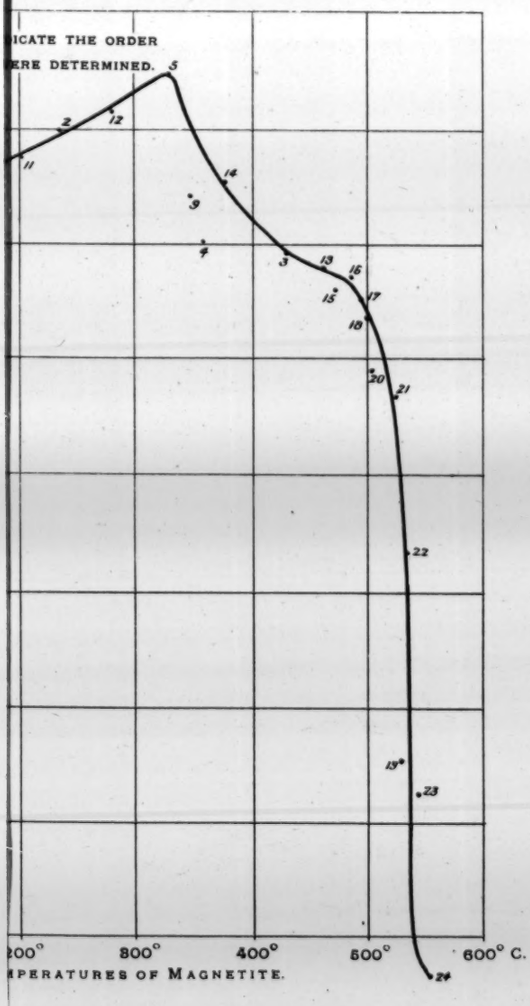
Curve (IV).

Corrected Kicks.



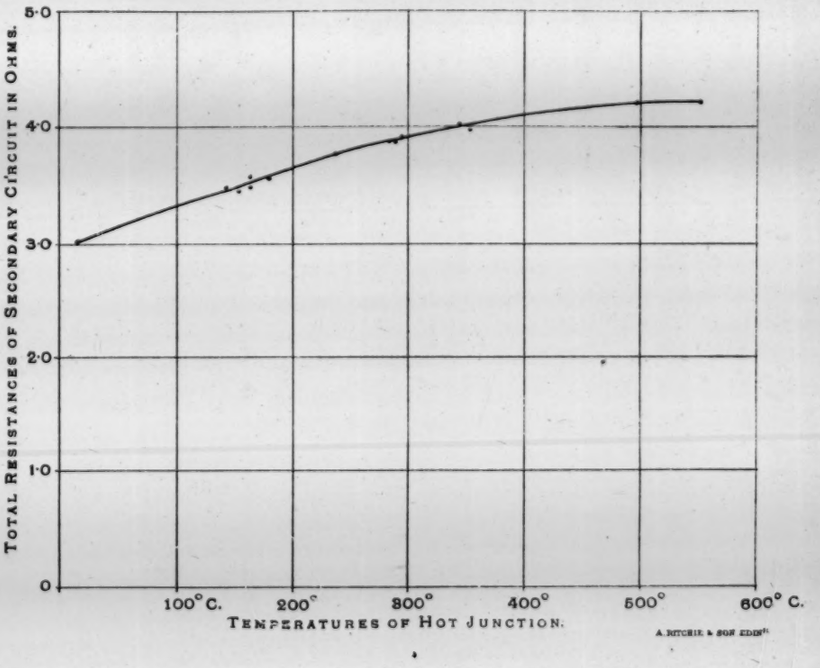
Curve (II).

Observed Kicks.



Curve (V).

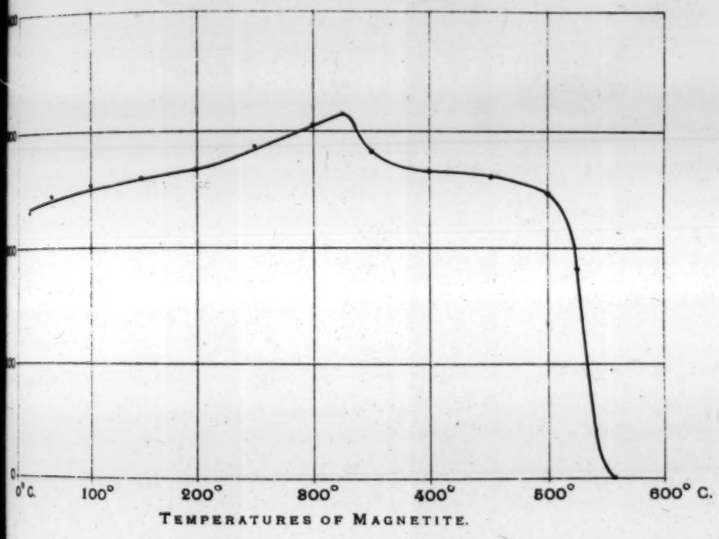
Resistance of Secondary Circuit.



A. Ritchie & Son Edin.

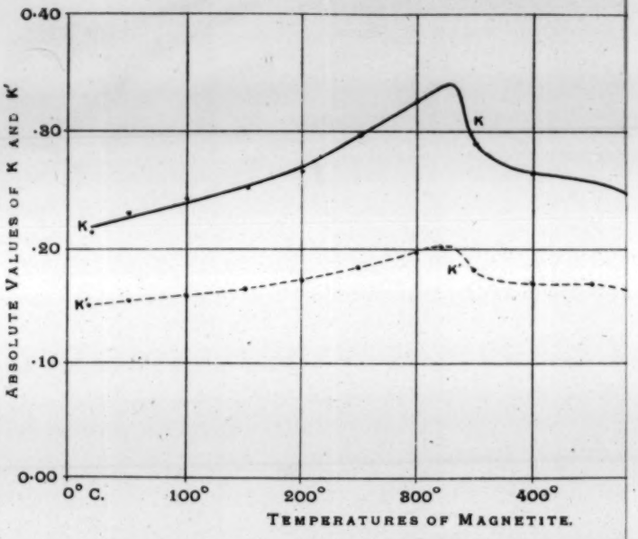
CURVE (VI).

ORDINATES PROPORTIONAL TO κ'
BEING PRODUCTS OF THOSE IN CURVES (IV) AND (V).



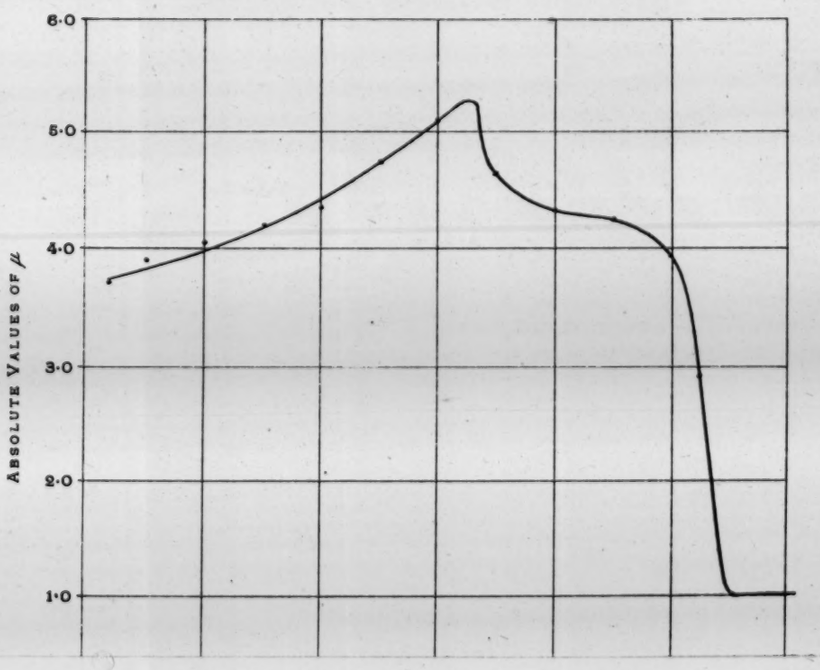
CURVE (VII).

SHOWING ABSOLUTE SUSCEPTIBIL
TRUE κ, APPARENT κ'.



CURVE (VIII).

SHOWING PERMEABILITIES.



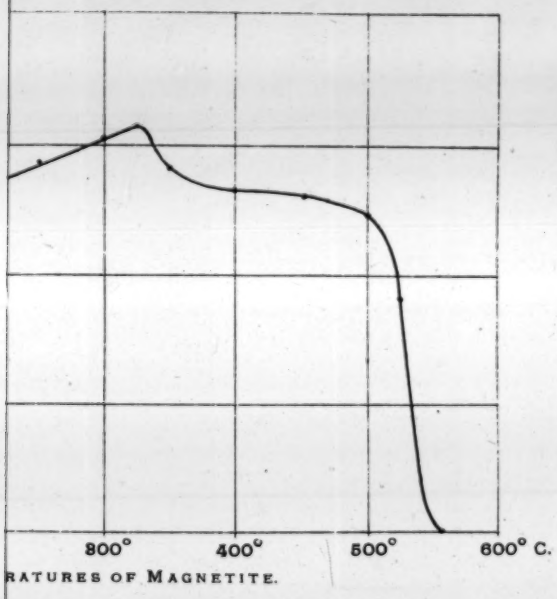
HE TEMPERATURE VARIATION OF THE MAGNETIC PERMEABILITY OF MAGNETITE.

PLATE III.

CURVE (VI).

ES PROPORTIONAL TO K'

F THOSE IN CURVES (IV) AND (V).

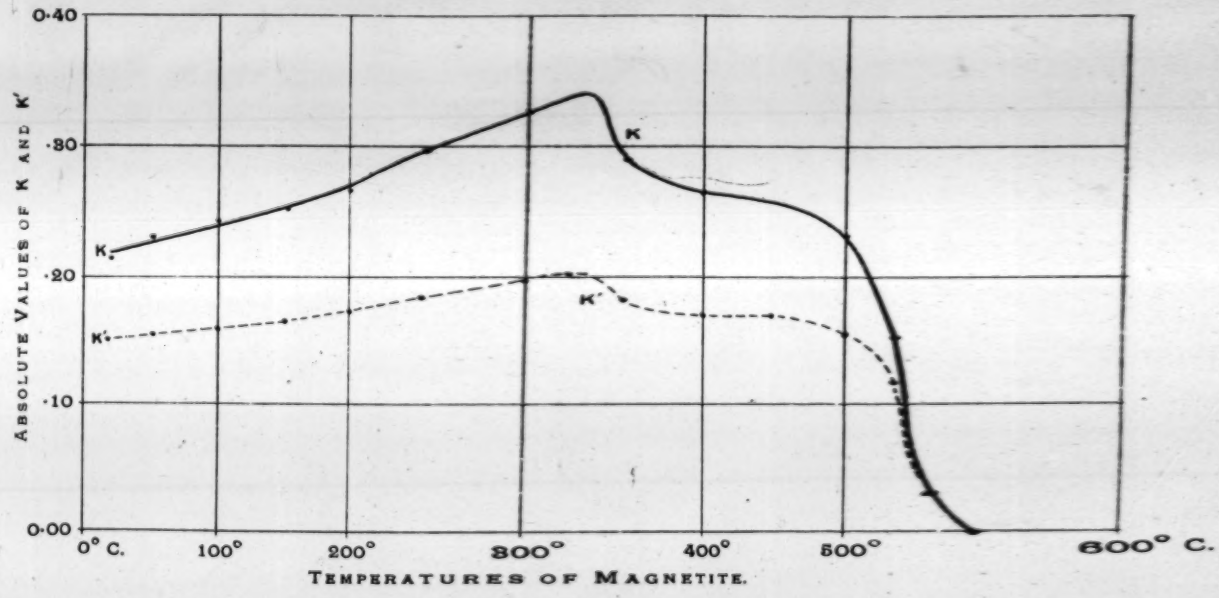


RATURES OF MAGNETITE.

CURVE (VII).

SHOWING ABSOLUTE SUSCEPTIBILITIES.

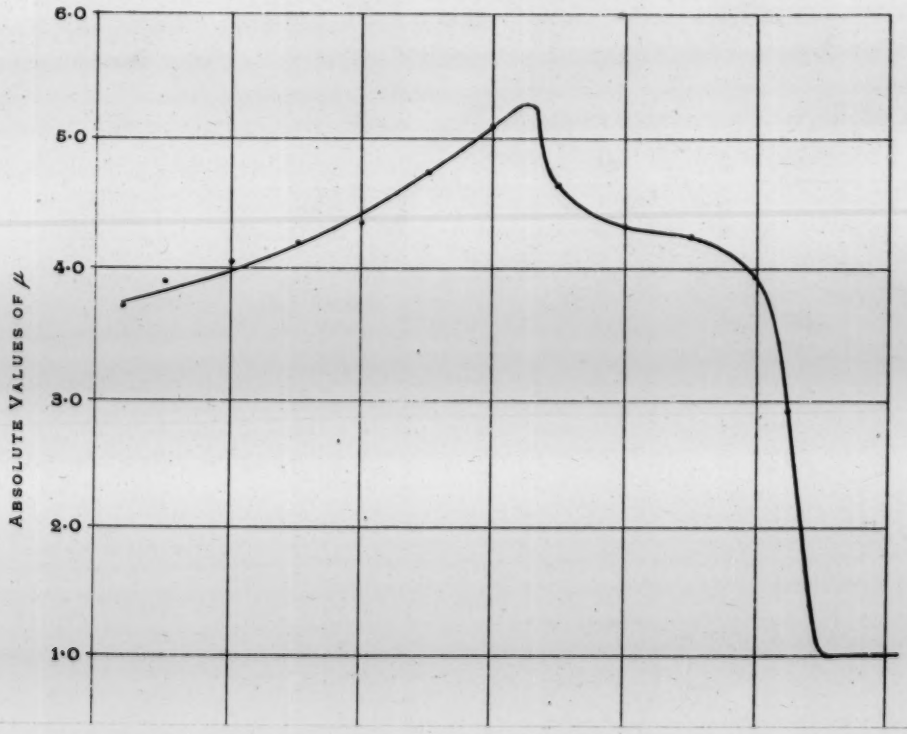
TRUE K, APPARENT K'.



TEMPERATURES OF MAGNETITE.

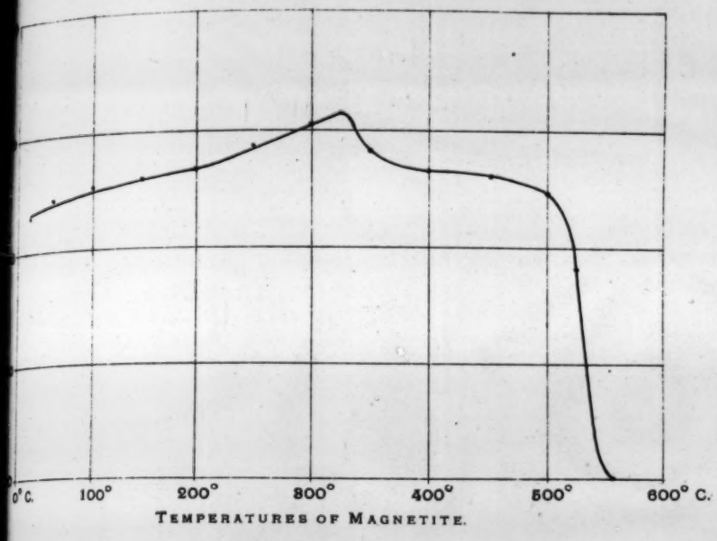
CURVE (VIII).

SHOWING PERMEABILITIES.



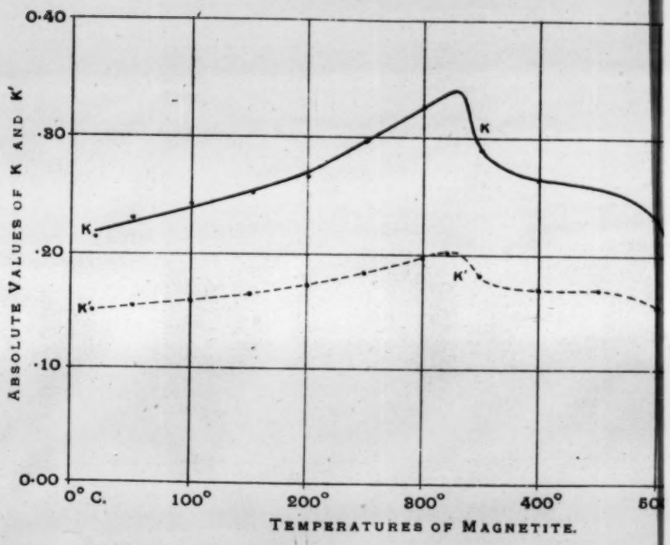
Curve (VI).

Ordinates proportional to κ' being products of those in curves (IV) and (V).



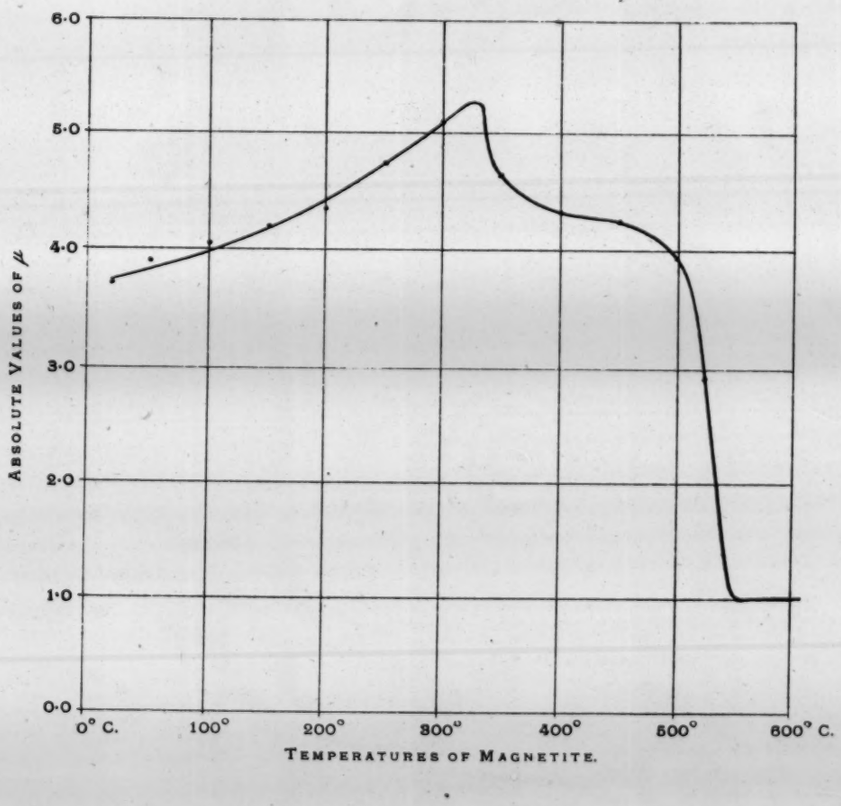
Curve (VII).

Showing absolute susceptibili
True κ, apparent κ'.



Curve (VIII).

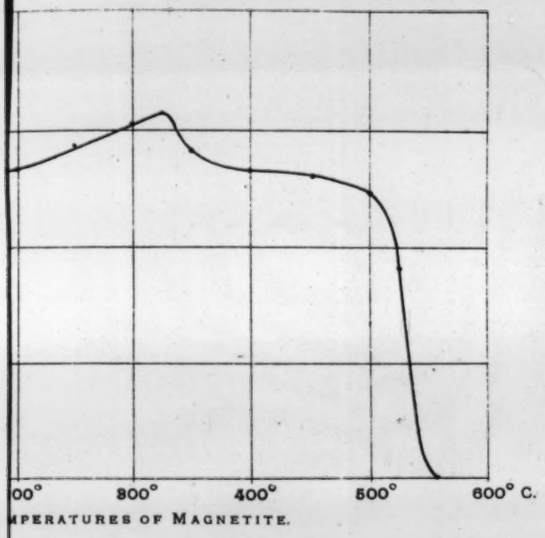
Showing permeabilities.



Curve (VI).

ATES PROPORTIONAL TO K'

S OF THOSE IN CURVES (IV) AND (V).

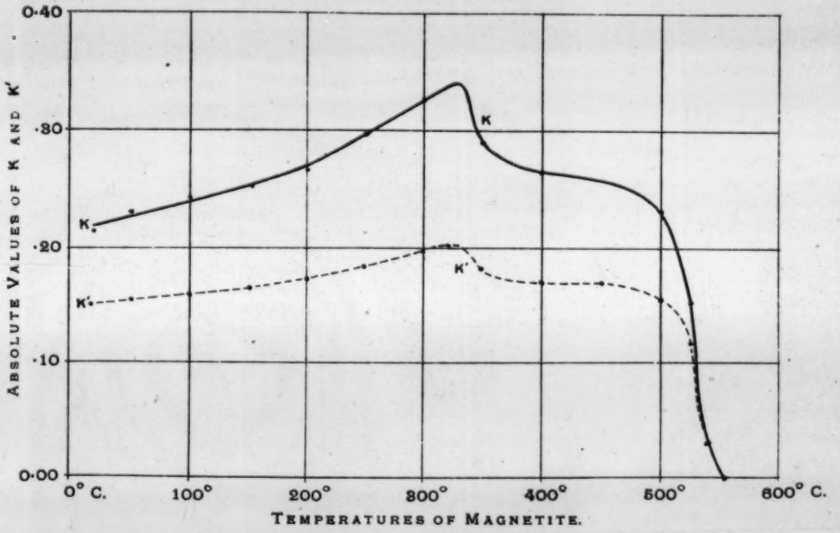


MPERATURES OF MAGNETITE.

Curve (VII).

SHOWING ABSOLUTE SUSCEPTIBILITIES.

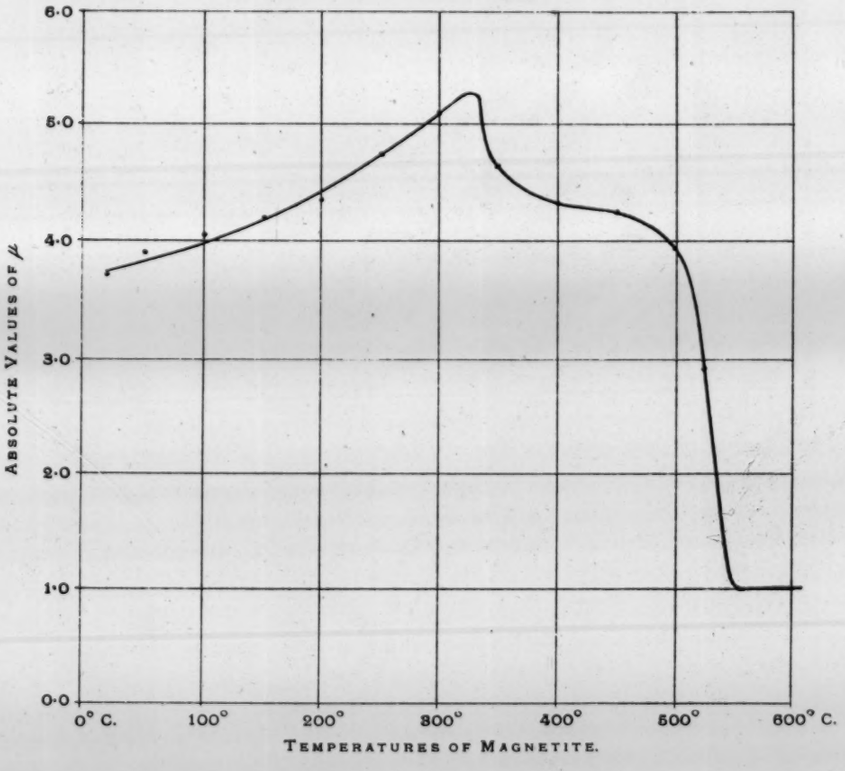
TRUE K, APPARENT K'.



TEMPERATURES OF MAGNETITE.

Curve (VIII).

SHOWING PERMEABILITIES.



TEMPERATURES OF MAGNETITE.

A. RITCHIE & SON, EDIN.ᴿ

XVI.—*The Weather, Influenza, and Disease: from the Records of the Edinburgh Royal Infirmary for Fifty Years.* By A. LOCKHART GILLESPIE, M.D., F.R.C.P.E.; Memb. Scot. Met. Soc.; Medical Registrar, Edinburgh Royal Infirmary. (With Six Plates.)

(Read January 20, 1896.)

In the following pages I have attempted to analyse various groups of figures derived from the records of the Royal Infirmary. When appointed Medical Registrar to the Infirmary in October 1891, it occurred to me that it might lead to interesting results if the admissions into the Medical Wards were contrasted with the varying states of the atmosphere, a sufficiently long time being taken to avoid the fallacies attendant on statistical generalisations from insufficient data. At first my intention had been to investigate the influence of the weather on the diseases of the principal systems, but as the work progressed I found that the repeated attacks of Epidemic Influenza so modified the results that I had perforce to take up the study of that disease in addition. The Infirmary year begins on the 1st of October; and, although the figures might have been calculated with some trouble for the year from the 1st of January, they have been left for the most part in their original form. The period to which most of the figures relate comprises the seven years from 1st October 1888 to 30th September 1895. Each case is noted as on admission, and each death as it occurred. Most of the figures are given as weekly totals. The year 1888–89 is included because no epidemic of Influenza occurred during it. In each of the other years epidemics were present.

The meteorological data have been obtained from the weekly reports of the Meteorological Office of London, and invariably refer to the East of Scotland as a district. The data are taken for the district, and not for Edinburgh alone, because the patients of the Royal Infirmary are drawn from the country as well as from the city. For some of these figures I have to thank Dr BUCHAN and Mr R. C. MOSSMAN.

The meteorological facts taken comprise the weekly type of weather, *i.e.*, cyclonic or anticyclonic, the extremes of temperature for the district for each week, and the mean weekly rainfall for the same district. The mean weekly temperature is also noted. More use is made of the extremes of temperature than of the mean, for I believe that rapid changes of temperature have a greater influence on disease than the actual mean.

General Facts with regard to the Admissions to the Medical Wards during the Seven Years.

The total number of cases admitted into the Medical Wards during the seven years under review reached 27,569, or a yearly average of 3938. The numbers admitted during the later years showed a very considerable increase over those of the earlier part.

The number of cases belonging to the different systems were then worked out. The systems chosen were (1) the Respiratory, which was considered as a whole, all the different diseases being grouped together, while, in addition, separate tables were constructed for cases of Pneumonia and Pleurisy; (2) the Circulatory; (3) the Urinary, in which, however, only cases of Kidney disease were included; (4) cases of Acute and Subacute Rheumatism; (5) the Nervous; and (6) the Digestive system. The number of deaths was also noted, but it must be remembered that the actual date of the death was recorded, not the date on which the case was admitted. A note was also made of the admissions of patients with Chorea, Appendicitis or Perityphlitis, and with Diabetes Mellitus. The figures for the last three diseases were too small to make an extended investigation into their relations worth the labour involved.

1. Total Admissions.

The total number of admissions were, as already stated, 27,569. But the number admitted during the individual years varied very considerably. The actual figures are :—

Year.	Patients Admitted.
1888–89	3,665
1889–90	3,530
1890–91	3,887
1891–92	3,776
1892–93	3,944
1893–94	4,078
1894–95	4,689
	27,569

These numbers are taken from the official returns, but unfortunately those for 1894–95 do not correspond properly with the preceding ones, as in that year the patients admitted into two small wards in the surgical hospital, but who were really medical cases, were for the first time entered under their proper designation. The numbers involved, however, are not sufficient to account for the enormous increase chronicled for that year.

2. The Admissions of Different Classes of Disease.

The following tables represent the number of cases admitted, arranged according to the system affected, or under the actual disease.

Table I.

Year	1888–89.	–90.	–91.	–92.	–93.	–94.	–95.	Total.	Weekly.
Respiratory System,	697	800	815	844	809	913	960	5838	15·96
Pneumonia,	106	140	141	189	183	182	173	1114	3·05
Pleurisy,	116	146	163	151	102	145	119	942	2·58
Cardiac,	310	261	268	387	400	370	395	2491	6·87
Kidney,	152	181	157	172	200	221	177	1260	3·44
Rheumatism,	54	103	82	59	107	181	168	754	2·04
Nervous,	612	590	687	579	679	690	683	4520	12·35
Digestive,	449	462	469	534	569	569	675	3727	10·21
Chorea,	28	39	60	41	38	46	62	314	0·86
Appendicitis,	10	17	21	21	32	44	72	226	0·61
Mortality,	331	358	362	266	422	370	429	2638	7·24

Table II.

	Totals.	Percentage to Total Admissions.	Yearly.	Weekly.
Respiratory,	5838	21·3	834	15·96
Pneumonia,	1114	4·04	159·1	3·05
Pleurisy,	942	3·43	134·5	2·58
Cardiac,	2491	9·01	355·8	6·87
Kidney,	1260	4·5	180	3·44
Rheumatism,	754	2·7	107·7	2·04
Nervous,	4520	16·34	645·7	12·35
Digestive,	3727	13·41	532·4	10·21
Chorea,	314	1·1	44·8	0·86
Appendicitis,	226	0·78	32·2	0·61
Mortality,	2638	9·59	376·8	7·24

These figures serve throughout the paper as means from which any deviations from the normal may be detected.

The next table gives the percentages between the same classes of disease and the total admissions for the different years, with the mean temperatures and the mean annual rainfalls added.

TABLE III.—*Showing the Percentage Proportion between Different Classes of Disease and the Total Admissions for Seven Years* 1888–95.

Year	1888–89.	-90.	-91.	-92.	-93.	-94.	-95.	Mean Total.	Weekly.
Mean temp., . . .	46·6	46·9	46·0	44·5	46·3	45·8	45·3	...	45·9
Mean rainfall, . . .	28·5	27·0	31·8	29·2	27·1	34·8	28·0	29·55	0·56
Totals, . . .	3665	3530	3887	3776	3944	4078	4689	3938	...
Weekly, . . .	70·4	67·8	74·7	72·6	75·8	78·4	90·1	...	75·5
Respiratory, per cent., . .	19·0	22·3	20·9	22·3	20·5	22·3	20·4	...	21·3
Pneumonia, „ . .	2·89	3·96	3·62	5·00	4·63	4·46	3·69	...	4·04
Pleurisy, „ . .	3·16	4·1	4·18	4·00	2·58	3·50	2·50	...	3·43
Circulatory, „ . .	8·4	7·3	9·4	10·2	10·1	9·07	8·40	...	9·01
Kidney, „ . .	4·1	5·1	4·03	4·50	5·07	5·40	3·50	...	4·5
Rheumatism, „ . .	1·4	2·94	2·09	1·56	2·70	4·40	3·50	...	2·7
Nervous, „ . .	16·6	16·8	17·6	15·3	16·8	16·8	14·5	...	16·34
Digestive, „ . .	12·2	13·0	12·0	14·1	14·4	13·9	14·3	...	13·41
Chorea, „ . .	0·76	1·10	1·50	1·08	0·96	1·10	1·30	...	1·1
Appendicitis, Perityphlitis, .	0·51	0·49	0·52	0·55	0·81	1·07	1·53	...	0·78
Mortality, per cent., . .	9·03	10·1	9·30	9·70	10·69	9·07	9·84	...	9·59

I could trace no connection between the mean temperature or rainfall and the admissions of any of the classes of disease enumerated above. On the other hand, the number of cases of both pneumonia and pleurisy was lower in proportion to the total admissions during the later years. The percentage of nervous cases also fell a little, while that of the digestive system showed indications of a slight increase. Cases both of acute rheumatism and of appendicitis and perityphlitis exhibited a marked increase in their numbers per cent. from the earlier to the later years.

3. THE INFLUENCE OF WEATHER ON THE ADMISSIONS.

To investigate the influence of the elements of weather on the incidence of disease, the weeks of the seven years were separated into those in which the type was mainly cyclonic, and into those during which the distribution of pressure was anticyclonic. In some cases I had to exercise my judgment with regard to the prevailing type,—that is to say, that in some instances where there were moderate gradients or small shallow local secondaries, the type was determined by the weather conditions accompanying them. The weeks were also divided into those in which the maximum temperature rose above 60° Fahr., and into those in which the thermometer did not reach that figure. The direction of the prevailing wind during each week was also noted, whether it was west by south, or east by north, but the results of this last item were so uniform, the direction of the wind had so little effect on the admissions that I have not burdened this paper with the details. The mean weekly rainfall also corresponded to the type

of weather very closely, and has not been made much use of in the sequel, in the fear that too much detail might obscure the main points of the communication.

In the following short table the weeks of the seven years have been divided into cyclonic and anticyclonic, and into those with a temperature which rose above 60° and those in which the temperature remained below the point.

Year.	Cyclonic.	Anticyclonic.	+60°.	−60°.
1888–89, ...	30	22	27	25
1889–90, ...	35	17	28	24
1890–91, ...	26	26	31	21
1891–92, ...	34	18	30	22
1892–93, ...	22	30	30	22
1893–94, ...	37	15	32	20
1894–95, ...	29	23	27	25
Total, . . .	213	151	205	159
Mean, . . .	30·4	21·5	29·2	22·7

During the seven years the type of weather was cyclonic in 30·5 of the fifty-two weeks on an average, and anticyclonic in 21·5. The temperature works out at very nearly the same figures, 29·2 weeks above, and 22·7 below 60°.

In Table IV. the relation between these meteorological factors and the weekly admissions is shown. The total number for each year is given above, the weekly means below, in each section.

First the ordinary average for the fifty-two weeks is shown, and then the average weekly admissions in relation to the type of weather and the temperature.

Cases of respiratory disease were admitted in larger numbers when the temperature remained below 60°, and when the type was cyclonic. The same holds good in the admissions of patients suffering from pleurisy, when considered separately. On the other hand, pneumonia was more prevalent in anticyclonic weather.

Reference to Table III. shows that the proportion of the total number of respiratory cases to the total number of admissions for all diseases was higher in three of the seven years 1890–92–94. These three years were marked by a greater prevalence of cyclonic weather than the other four, as reference to the table above will show.

Patients suffering from disease of the heart were admitted in greater numbers when the barometer was low and the temperature high. The same may be said of the kidney cases, while rheumatic affections were more numerous in anticyclonic weather and when the thermometer did not reach 60°. The figures for the nervous cases show a slight increase during anticyclonic weather and when the temperature was above 60°; the same applies to the digestive system. Cases of chorea and appendicitis were admitted in greater numbers when the barometric type was anticyclonic, while the

weekly number of deaths in the Medical Wards was also greater with a high barometer, a slight increase being noted in warm as compared with colder weeks.

Some objection might be taken to the inclusion of cases of chronic disease among the other figures, but it must be remembered that most cases of chronic disease admitted into the Infirmary were taken in for an acute or sub-acute exacerbation.

TABLE IV.—*Showing the Weekly Admissions in connection with the Type of Weather and the Temperature for Seven Years, with the Means added.*

Year	1888–89.	–90.	–91.	–92.	–93.	–94.	–95.	Total.	Mean.
Respiratory.									
Total, . . .	697	800	815	844	809	913	960	5838	834
Weekly, . .	13·3	15·3	15·3	16·2	15·5	17·5	18·6	111·76	15·96
Cyclonic, . .	12·9	19·5	15·0	17·0	13·9	17·9	18·0	114·2	16·31
Anticyclonic, .	14·17	13·9	16·9	14·6	16·6	16·0	19·0	111·2	15·88
Temp. below 60°, .	13·8	17·2	17·8	18·3	16·7	18·8	19·3	121·9	17·41
Temp. above 60°, .	13·0	13·7	14·5	13·5	14·5	13·1	17·3	99·6	14·21
Pneumonia.									
Total, . . .	106	140	141	189	183	182	173	1114·0	159·1
Weekly, . .	2·03	2·69	2·71	3·63	3·51	3·5	3·3	21·37	3·05
Cyclonic, . .	1·8	2·77	3·0	3·5	2·73	3·3	3·3	20·4	2·91
Anticyclonic, .	2·4	2·55	2·42	3·69	4·13	3·6	3·3	22·09	3·15
Temp. below 60°, .	2·16	2·96	2·8	3·83	3·15	3·1	3·4	21·40	3·05
Temp. above 60°, .	1·92	2·42	2·63	3·33	3·76	4·00	3·2	21·26	3·03
Pleurisy.									
Total, . . .	116	146	163	151	102	145	119	942	134·5
Weekly, . .	2·23	2·8	3·13	2·9	1·9	2·78	2·2	17·94	2·56
Cyclonic, . .	2·52	2·93	3·15	3·36	1·50	2·40	2·2	18·06	2·58
Anticyclonic, .	1·64	2·6	3·11	2·1	2·26	3·03	2·2	16·94	2·42
Temp. below 60°, .	2·25	2·92	3·18	3·15	2·13	2·70	2·20	18·53	2·64
Temp. above 60°, .	2·21	2·69	3·09	2·50	1·83	2·80	2·30	17·42	2·48
Cardiac.									
Total, . . .	310	261	368	387	400	370	395	2491	355·8
Weekly, . .	5·96	5·01	7·07	7·44	7·69	7·3	7·63	48·1	6·87
Cyclonic, . .	6·00	5·27	6·65	8·36	7·18	7·40	7·60	48·46	6·92
Anticyclonic, .	5·94	4·90	7·30	6·90	8·00	5·70	7·50	46·24	6·6
Temp. below 60°, .	6·08	4·96	7·20	7·25	7·59	6·50	7·80	47·38	6·76
Temp. above 60°, .	5·89	5·34	6·80	7·75	7·70	7·60	7·40	48·48	6·92
Kidney.									
Total, . . .	152	181	157	172	200	221	177	1260	180
Weekly, . .	2·9	3·40	3·00	3·30	3·80	4·30	3·40	24·1	3·44
Cyclonic, . .	2·6	3·50	2·70	3·2	3·9	4·40	3·80	24·2	3·45
Anticyclonic, .	3·4	3·40	3·30	3·30	3·80	3·80	2·80	23·8	3·40
Temp. below 60°, .	2·5	3·10	2·40	2·70	4·10	4·20	3·60	22·6	3·22
Temp. above 60°, .	3·2	3·70	3·30	3·70	3·60	4·20	3·10	24·8	3·54

TABLE IV.—*Showing the Weekly Admissions in connection with the Type of Weather and the Temperature for Seven Years, with the Means added*—continued.

Year	1888-89.	-90.	-91.	-92.	-93.	-94.	-95.	Total.	Mean.
Rheumatism.									
Total, . . .	54	103	82	59	107	181	168	754	107·7
Weekly, . .	1·03	1·98	1·57	1·11	2·05	3·40	3·20	14·34	2·04
Cyclonic, . .	0·94	1·98	1·76	1·03	2·04	3·30	2·10	13·15	1·87
Anticyclonic, .	1·11	2·10	1·46	1·26	2·13	3·80	4·50	16·36	2·33
Temp. below 60°, .	1·25	1·96	1·90	1·25	2·31	3·40	3·50	15·57	2·22
Temp. above 60°, .	0·78	1·98	1·41	0·9	1·93	3·40	2·80	13·2	1·88
Nervous.									
Total, . . .	612	590	687	579	679	690	683	4520	645·7
Weekly, . .	11·7	11·3	13·2	11·0	13·0	13·2	13·1	86·5	12·36
Cyclonic, . .	11·5	11·2	12·0	10·9	13·9	13·6	13·2	86·3	12·32
Anticyclonic, .	12·1	11·5	14·4	11·4	12·4	12·2	13·0	87·00	12·42
Temp. below 60°, .	12·8	10·1	13·3	11·2	13·0	13·6	11·6	85·60	12·2
Temp. above 60°, .	10·7	12·6	13·0	11·0	13·3	13 0	14·5	88·1	12·58
Digestive.									
Total, . . .	449	462	469	534	569	569	675	3727	532·4
Weekly, . .	8·6	8·9	9·0	10·2	10·9	10·9	13·0	71·5	10·21
Cyclonic, . .	8·9	9·0	9·0	9·9	10·0	10·0	12·8	69·6	9·94
Anticyclonic, .	8·5	8·6	8·9	10·4	11·5	11·3	13·1	72·3	10·32
Temp. below 60°, .	9·3	8·8	8·3	9·5	10·9	10·9	13·0	70·7	10·1
Temp. above 60°, .	7·9	8·7	9·4	10·6	10·9	10·9	13·2	71·6	10·22
Chorea.									
Total, . . .	28	39	60	41	38	46	62	314	44·8
Weekly, . .	0·53	0·75	1·15	0·78	0·73	0·88	1·19	6·01	0·86
Cyclonic, . .	0·53	0·60	1·00	0·61	0·81	0·81	1·27	5·63	0·80
Anticyclonic .	0·53	1·05	1·30	1·11	0·66	1·06	1·08	6·79	0·97
Temp. below 60°, .	0·60	0·66	1·28	0·59	0·77	1·00	1·28	6·18	0·88
Temp. above 60°, .	0·47	0·81	1·06	0·93	0·70	0·81	1·10	5·88	0·84
Appendicitis and Perityphlitis.									
Total, . . .	19	17	21	21	32	44	72	226	32·2
Weekly, . .	0·36	0·32	0·4	0·4	0·61	0·84	1·38	4·31	0·61
Cyclonic, . .	0·43	0·25	0·34	0·32	0·63	0·77	1·51	4·25	0·60
Anticyclonic, .	0·27	0·47	0·46	0·55	0·6	1·00	1·21	4·56	0·65
Temp. below 60°, .	0·48	0·20	0·40	0·22	0·63	0·75	1·36	4·04	0·57
Temp. above 60°, .	0·25	0·42	0·41	0·53	0·60	0·90	1·40	4·51	0·64
Mortality.									
Total, . . .	331	358	362	366	422	370	429	2638	376·8
Weekly, . .	6·36	6·88	6·96	7·03	8·11	7·11	8·24	50·69	7·24
Cyclonic, . .	6·00	7·21	6·92	6·87	7·77	7·10	7·30	49·17	7·02
Anticyclonic, .	7·05	6·35	7·00	7·31	8·20	7·00	9·40	52·31	7·47
Temp. below 60°, .	6·20	6·69	6·80	6·65	7·90	7·40	8·60	50·24	7·17
Temp. above 60°, .	6·50	7·07	7·06	7·65	8·26	6·90	8·20	51·64	7·27

Influenza.

Sir Arthur Mitchell and Dr Buchan published two papers in the *Journal of the Scottish Meteorological Society* in the numbers for 1889 and 1890, dealing in an exhaustive manner with the two epidemics of Influenza which occurred in London, as well as in the rest of the country, during the course of these years. By making use of the mortality returns they deduced several very striking facts; while, on further comparing these returns with the weather conditions for periods both before and during the epidemics, they found very little connection between the two. Their figures dealt with the deaths due to or occurring with the prevalence of influenza, and they remarked that some further statistics dealing with actual cases of the disease would be of value.

Influenza has been epidemic in this country on twenty-three occasions from the year 1510 to the year 1890. A considerable interval intervened between the great majority of the attacks.

List of Epidemics.

1510	1675	1767	1831	1855	1893
1557	1709	1775	1833	1857–8	1893–4
1580	1732–3	1782	1836–7	1889–90	1895
1587	1743	1789–90	1847–8	1891	...
1591	1762	1803	1850–1	1891–2	...

It is worth noting that five epidemics occurred in the sixteenth century, only one in the seventeenth, eight in the eighteenth, and, up to 1895, as many as fourteen in the present century. Since the winter of 1889–90 we have passed through no fewer than six distinct epidemics, varying in intensity. At no period from the beginning of the sixteenth century until six years ago have there been so many attacks in so short a time. From 1510 to 1889 the number of years which intervened between the different epidemics averaged sixteen. In six instances only the attacks followed one another at all closely, viz., in 1587, 1591, 1831, 1833, and in 1855, 1857–8. The occurrence of influenza in epidemic form on so many separate occasions during the last six years brings the number of recorded outbreaks since 1510 up to twenty-eight in 385 years, or one in every 13·7 years. The occurrence of six well-marked epidemics of influenza during the last six years must have had a great influence on the incidence of disease in the same period, when we remember the vigorous action of the poison on the respiratory, the circulatory, and the nervous systems. From the statistics of the Edinburgh Royal Infirmary it is clear that sixty-eight weeks out of the 312 from 1st Oct. 1889, to 30th Sept. 1895, were marked by the prevalence of influenza in epidemic form, that is to say, one week in every four and a half. In order that these figures might be verified Dr K. M. Douglas kindly gave me the numbers of cases of this disease occurring among the staff of the Post Office in Edinburgh for the same period. The figures obtained from the Post Office are particularly valuable, as the total number of those who could be attacked is known, the cases are all drawn from one class, and that

class is, by reason of its work, the first to be attacked among the community. On the other hand, the numbers being limited, the end of the epidemic does not correspond with the end of the attack when all classes are involved, as is the case in the Infirmary. The data, then, derived from the Post Office returns are of value in arriving at the true date of the onset, but not of the duration of the epidemic. In dealing with the records of the Infirmary it must also be remembered that cases of influenza are rarely admitted simply as influenza, as they are usually unsuitable for treatment in a hospital which does not admit cases of infectious disease. In fact, most of the cases are admitted for acute complications, of which the cause may not be found until after residence in hospital, when a history of a preceding attack of influenza is elicited.

Sir ARTHUR MITCHELL and Dr BUCHAN, in the papers already quoted, point out that the epidemics of influenza recorded in this country have usually occurred during the winter months, and have then been accompanied by complications which were chiefly respiratory and circulatory in type. In spring epidemics the nervous centres showed a greater tendency to be implicated; and in the only summer epidemic previously recorded in this country during the nineteenth century, diarrhœal disorders were very prevalent. These authors were unable to trace any connection between the weather, as regards the element of temperature, and the epidemics of 1889–90.

GENERAL DESCRIPTION OF THE SIX EPIDEMICS.

In the records of the Edinburgh Royal Infirmary from 1888 to 1895, the first case of influenza admitted into the hospital was registered in the week ending the 21st of December 1889, one week later than the first death registered in London from that disease. The first case diagnosed as influenza among the employees of the Post Office occurred on 20th December, a fact which corresponds so closely with the Infirmary records that the beginning of the first epidemic may be definitely stated to be the week 15th–21st December 1889. The maximum in the Post Office occurred in the following week, in the Infirmary not till the second week of 1890, a week earlier than the maximum *mortality* from influenza in London. The Post Office epidemic had practically ceased by the middle of January, but cases continued to be admitted into the Infirmary until the week ending 15th February. The epidemic may therefore be regarded as having lasted for nine weeks. Single cases were reported in the Infirmary up to the end of June.

No further entries were made in the books until the third week of November 1890, when two isolated cases were admitted. Scattered cases continued to be taken in until May 1891, when the numbers increased considerably, and only began to diminish early in July. In the Post Office, patients were invalided owing to influenza in rather scanty numbers throughout March and April, and in greater numbers in May and June. The epidemic, however, never reached any great proportions. In London it started in the middle of April. A glance at the numbers of respiratory cases treated at the Infirmary

for the month of April shows that it was much above the average. The epidemic of this year may therefore be assumed to have begun in Edinburgh and district about the middle of the month, and to have gone on until the end of the week ending 11th July, a period of thirteen weeks.

The admission of cases of influenza practically ceased from the date last mentioned until 25th October 1891. During the next sixteen weeks patients suffering from influenza were admitted in large numbers. This attack proved to be the worst of the six, with regard to the results, in the Infirmary. The maximum may be assigned to the week ending 5th December 1891, and the end of the epidemic to the week ending 13th February 1892, although scattered cases were taken in for some time afterwards. The Post Office records agree in almost every particular with those from the Infirmary. The epidemic commenced at the same date, reached its highest level during the same week, but diminished sooner, as might be expected.

The attack which occurred in the spring of 1893 can hardly be dignified with the name of an epidemic, if the number of patients admitted for the disease be alone considered. A great increase, however, took place in the admissions of respiratory cases, an increase which, being out of season, must be looked upon as due to some abnormal cause. In the Post Office, influenza was present in a mildly epidemic form during March and April, commencing on the 15th of March. From this fact, and owing to the rise in the respiratory admissions after 11th March, the beginning of this epidemic may be assigned to the week commencing at that date. A short attack, lasting to the end of April, it only continued for seven weeks.

The fifth epidemic of the series began towards the end of October 1893 and lasted until the end of January 1894. I have given the date of the commencement of this epidemic on 15th October, as agreeing with the Infirmary records, but the postmen were not affected until the 21st. The maximum in the Post Office occurred in the second and third weeks of November, while in the Infirmary it was not reached until the first week of December.

List of Epidemics.

Year.	Duration.	Winter.	Spring.	Summer.
1. 1889–90, . .	9 weeks	Dec. 15–Feb. 15	...	...
2. 1891, . . .	13 ,,	...	...	Apr. 12–July 11
3. 1891–92, . .	16 ,,	Oct. 25–Feb. 13	...	...
4. 1893, . . .	7 ,,	...	Mar. 11–Apr. 28	...
5. 1893–94, . .	16 ,,	Oct. 15–Jan. 31	...	...
6. 1895, . . .	7 ,,	...	Feb. 11–Mar. 31	...
Total weeks, .	68	41	14	13

The other months of 1894 were comparatively free from influenza, a few cases being recorded in December. In February 1895 it again became epidemic, and reached its

height in the middle of March. The actual duration of the attack was only seven weeks, viz., from 11th February to 31st March. The Post Office figures coincide in every particular.

Of the six epidemics, three occurred in winter, two in spring, and one in early summer. If the total number of weeks be added together in which influenza was epidemic during the last six years, we arrive at the large figure of sixty-eight,—that is, one in every four and a half.

The spring epidemics were, as a rule, of shorter duration than those occurring in the winter, the one summer attack holding a mediate position.

For the sake of clearness, the subjects of the weather on influenza, and of the influence of influenza on disease, are taken up *seriatim* in the sequel, first in connection with each epidemic, secondly with regard to the epidemics treated together.

Number of Cases involved.

Before considering the relations between the epidemics and the weather, it would perhaps be as well to give the number of patients attacked during the course of each epidemic, both in the Infirmary and in the Post Office. As the total number of the possible patients in the Post Office is close upon 1000 (probably a little above that figure), the percentage attack can be calculated.

Number of Cases.

Year.	Infirmary.	Post Office.	Percentage in Post Office.
1889–90, ...	26	95	9·5
1891, ...	28	35	3·5
1891–92, ...	189	139	13 9
1893, ...	19	15	1·5
1893–94, ...	59	116	11·6
1895, ...	44	74	7·4
Total, . .	365	474	47·4
Per year, . .	60·8	79·0	7·9

The three winter epidemics have therefore been the most severe, judging by the number of cases of pure influenza which were recorded during their course.

The Weather and Influenza.

1. The first epidemic, which began on the 15th of December 1889, and continued for nine weeks, was preceded by six weeks of cyclonic weather, which was not, however, accompanied by a heavy rainfall. The temperature had been a little above the mean

for the seven years, and did not show any marked diurnal variations. Throughout the course of the epidemic the type continued to be almost exclusively cyclonic, with a heavy rainfall, a high temperature, and a great deficiency of sunshine. The four weeks immediately following were also chiefly cyclonic, but with a smaller precipitation. The wind throughout was westerly, except during the last week of the epidemic and the next two, when it was from the east. (The actual figures for these statements will be found in Table V.)

2. The summer epidemic of 1891, from 13th April to 11th July, followed a fine winter and spring, during which anticyclonic conditions were largely prevalent. Anticyclones reigned supreme from the middle of November to the end of February, practically without a break. The extremes of temperature were widely separated from each other, and the rainfall was small. In March barometric depressions from the Atlantic governed the type of weather, with an increased rainfall. It was during this weather that the respiratory cases in the Infirmary began to increase, but it was not until the type again changed to the anticyclonic that the epidemic could be said to have commenced. A study of the figures for the six weeks preceding shows that the rainfall was above the normal, the temperature low, and the percentage of sunshine small. When the epidemic began, the type was anticyclonic. While the epidemic lasted the type remained largely anticyclonic, or with small local cyclones, the rainfall was not excessive, and the sunshine plentiful. During the last two weeks the rainfall became very heavy, and continued so for the four following weeks, with cyclonic weather and west winds. The temperature throughout remained high. In this case, then, the epidemic was preceded by wet weather and a low barometer, took place in dry weather (if the last two weeks be missed out, when the attack was declining), and was followed by wet, cyclonic weather in its turn.

3. The great winter epidemic of 1891–92 (25th October to 13th February) followed an extremely wet and broken autumn. September and October were particularly wet, though not cold, while the chief type of weather was cyclonic. If the figures for the six weeks preceding this epidemic be consulted, it will be seen that their mean rainfall was nearly an inch and a half, and the weather cyclonic throughout. The maximum temperatures registered during these weeks were above 60°. Simultaneously with the establishment of an anticyclone, with east wind, practically no rain, and a diminution in the temperature, the epidemic commenced. The anticyclone only lasted for two weeks, and during the rest of the epidemic the type was mainly cyclonic. The rainfall and amount of sunshine registered varied very markedly, but had no influence on the course of the disease. The maximum thermometer never rose above 60°, while the minima on several occasions fell below 10°. As the epidemic subsided the weather changed its character, not so much in its type, which was very variable, as in the diminished rainfall and the presence of great extremes in the temperature. The advent of warmer weather and more equable days saw the disappearance of the epidemic. A long period of cyclonic conditions, extending over ten weeks, in the autumn of the

same year, accompanied by a heavy rainfall, was marked by the occurrence of a few cases of influenza towards its close. No further cases, however, were registered until the spring of the next year. The epidemic of 1891–92 was therefore ushered in, after a preceding period of cyclonic weather with a heavy rainfall, by an accompanying change to anticyclonic conditions, but, unlike the last, it declined at a time when there was no excessive rainfall.

4. The fourth epidemic, although small in extent, seems to me to be the most interesting of the series. The temperature in the first two weeks of January 1893 fell to a very low point, under the influence of anticyclones which had persisted from the middle of December. In the third week of the year the barometer was affected by depressions to the west and north of our islands. These continued until the week commencing on the 5th of March, when anticyclonic conditions again resumed their sway, and continued unchecked until 23rd June, sixteen weeks later. Of the six weeks which preceded the epidemic, five were cyclonic in type, with a heavy rainfall, and a high temperature for the time of year. The last week before the outbreak was anticyclonic, and such conditions continued throughout the epidemic, with practically no rainfall until the last two weeks. The temperature remained uniformly high, rising above 70° in the last weeks of the outbreak. The weather for the four weeks after the subsidence of the epidemic continued to be anticyclonic in type, but with a slightly increased rainfall, less sunshine, and a greater mean temperature.

The fourth epidemic was therefore preceded by a wet period, ushered in by dry weather, accompanied by great heat, and its close occurred in slightly wetter weather, but under anticyclonic conditions.

5. The middle of October 1893 saw the advent of still another outbreak, the third of the winter epidemics. The six weeks before may be divided into two parts. The first four were influenced by cyclones, and were consequently warm and wet; the last two—that is, those immediately preceding the attack—were anticyclonic, colder, but still with a considerable rainfall. Throughout the sixteen weeks during which the influenza lasted, the weather remained cyclonic, with a heavy rainfall. At the close of this period the precipitation became very large—2·2 inches in two weeks. The four following weeks were also very wet, with a mean of 1·32 inches. Coincident with this heavy rainfall, the epidemic subsided. The fifth epidemic, therefore, began after a short anticyclone had become established over our islands, continued during a long spell of cyclonic weather with a considerable rainfall, but was, so to speak, drowned out by the heavy rains of the last two weeks of January and of the whole of February.

6. The sixth and last epidemic of which this paper treats took place in the spring of 1895 (11th February to 31st March), following a period of severe cold, and persisting through, for the first two weeks, a still more intense frost. In this case, again, the preceding weeks were cyclonic in character, with a marked rainfall, and with a great deficiency of sunshine. And again the epidemic began on the establishment of anticyclonic conditions. The rainfall was very small until the last two weeks of the

epidemic,—indeed, the precipitation of these two exceeded the total of the other five. Cyclones prevailed in the weeks after, with a very moderate rainfall. The sixth visitation of our modern plague thus commenced after cold and wet weather, continued in very cold but drier weather, and subsided in warmth with a moderate rainfall.

TABLE V.—*Meteorological Conditions prevailing before, with, and after the Different Influenza Epidemics.*

Period.	Type.		Mean Temperature.	Mean Rainfall.	Percentage Sunshine.
	Cyclonic.	Anticyclonic.			
1. *Epidemic of* 1889–90.					
6 weeks before, . .	6	0	41·06	0·21	23·5
2 first weeks, . . .	1	1	40·85	0·5	6·0
9 weeks of epidemic, .	7	2	39·36	0·7	19·4
Last 2 weeks, . . .	1	1	36·4	0·25	30·0
Next 4 weeks, . . .	2	2	39·36	0·4	23·75
2. *Epidemic of* 1891.					
6 weeks before, . .	5	1	37·08	0·58	28·5
First 2 weeks, . . .	0	2	41·3	0·15	42·0
13 weeks of epidemic, .	6	7	49·07	0·38	34·8
Last 2 weeks, . . .	1	1	57·1	0·85	30·0
Next 4 weeks, . . .	3	1	57·12	0·67	26·5
3. *Epidemic of* 1891–92.					
6 weeks before, . .	6	0	49·92	1·42	29·2
First 2 weeks, . . .	0	2	41·75	0·05	24·0
16 weeks of epidemic, .	11	5	38·01	0·6	21·9
Last 2 weeks, . . .	1	1	40·1	0·3	31·5
Next 4 weeks, . . .	3	1	32·3	0·5	20·2
4. *Epidemic of* 1893.					
6 weeks before, . .	5	1	39·23	0·63	25·0
First 2 weeks, . . .	0	2	41·38	0·1	55·0
7 weeks of epidemic, .	0	7	44·61	0·18	45·0
2 last weeks, . . .	0	2	47·75	0·3	36·5
Next 4 weeks, . . .	0	4	51·32	0·27	33·0
5. *Epidemic of* 1893–94.					
6 weeks before, . .	4	2	49·65	0·63	35·3
First 2 weeks, . . .	2	0	49·45	0·5	27·0
16 weeks of epidemic, .	13	3	39·77	0·66	19·6
Last 2 weeks, . . .	2	0	37·3	1·1	24·0
Next 4 weeks, . . .	4	0	38·0	1·32	33·0
6. *Epidemic of* 1895.					
6 weeks before, . .	5	1	29·35	0·58	16·6
First 2 weeks, . . .	0	2	26·45	0·15	41·0
7 weeks of epidemic, .	3	4	35·24	0·42	26·5
Last 2 weeks, . . .	2	0	41·6	0·9	21·5
Next 4 weeks, . . .	3	1	43·87	0·35	32·3

The preceding table (Table V.) gives the figures for the different epidemic periods, and for the weeks immediately preceding and following them. A glance at the table shows that the conditions were very variable in many respects, regular in others. The most constant condition was the decreased rainfall at the time when the disease was becoming epidemic. Another point that may be noted was the prevalence of anticyclonic weather at that time. The outbreaks of 1889–90 and of 1893–94 continued during wet weather; in the four other epidemics the rainfall during the continuance of the attack was very small.

Reference to the next table (Table VI.) makes several of these points much clearer. In this table the six weeks before each epidemic are considered together, and the same is done with the other different periods during and after the attacks. The mean for the same weeks for the seven years has also been worked out, and placed alongside the other figures for reference. The first thing which will attract attention is great disproportion between the number of weeks before the epidemics in which the type of weather was cyclonic to those in which the type was anticyclonic,—cyclonic 31, anticyclonic 5, in the thirty-six weeks. The mean for these weeks in the seven years was 26 to 10. The temperature for the preceding periods of six weeks was lower

TABLE VI.—*Meteorological Conditions prevailing during the Total Epidemic Periods.*

	Cyclonic.	Anticyclonic.	Mean Temperature.	Mean Rainfall.	Percentage Sunshine.
1. *The* 36 *weeks preceding the six attacks.*					
The 36 weeks, ...	31	5	41·37	0·67	26·3
Mean for same weeks in 7 years, . . .	26	10	43·01	0·56	...
2. *The first* 2 *weeks of all the Epidemics.*					
The 12 weeks, ...	3	9	40·22	0·24	32·5
Mean for same weeks in 7 years, . . .	9	3	41·27	0·56	...
3. *The* 68 *weeks of the Epidemics.*					
The 68 weeks, ...	40	28	41·21	0·47	27·8
Mean for same weeks in 7 years, . . .	40	28	41·31	0·53	...
4. *The last* 12 *weeks of the Epidemics.*					
The 12 weeks, ...	7	5	43·82	0·61	28·9
Mean for same weeks in 7 years, . . .	7	5	42·36	0·53	...
5. *The* 24 *weeks following the Epidemics.*					
The 24 weeks, ...	16	8	43·28	0·56	28·12
Mean for same weeks in 7 years, . . .	14	10	43·08	0·49	...
6. *The* 36 *weeks* (4 *and* 5) *at close of Epidemics.*					
The 36 weeks, ...	23	13	43·47	0·58	27·5
Mean for same weeks in 7 years, . . .	21	15	42·84	0·5	...

than the mean, while the rainfall was higher. The first two weeks of each attack, taken collectively, were characterised by very different weather conditions. During these 12 weeks, anticyclones prevailed in 9, cyclones in only 3,—exactly opposite to the normal conditions in the mean of seven years. The temperature was again lower, while the rainfall was less than half the mean, and about a third of the rainfall for the preceding weeks. The distribution of barometric pressure for the 68 weeks of the epidemics was normal, a remark which also applies to the mean temperature, while the rainfall was slightly less. If the last two weeks of each of the epidemic periods be considered separately from the total, we find that the type was normal, the rainfall heavier, and the temperature a degree higher than the means for the same weeks in seven years.

I do not wish to draw any conclusions from these facts, but simply to state that the figures adduced seem to suggest that a type of weather which is liable to cause catarrhs and other affections of the respiratory tract precede the epidemics, but that the occurrence of influenza in *epidemic form* does not appear to take place until another and drier type has been established. In the preceding period evidences that the disease is present are not wanting, but the number of cases are few. As the weather changes the numbers go up with a rush. I had expected to find more evidence of excessive rainfall at the close of the attacks than I did, for this was only marked in four out of the six.

A suggestion has been made that the cause of influenza might be disseminated, apart from those cases carried by persons and by infected articles, by the currents of air, especially by those induced by the state of barometric pressure termed anticyclonic. The great majority of the pandemics of influenza have travelled over Europe from east to west at that time of the year when the weather of the continent was dominated by the great winter anticyclone which is almost constant at that period over Russia and Siberia. The air, following the well known rule that in anticyclonic systems the currents flow out from the centre, is constantly flowing from east to west from Russia over the countries of Central Europe, and it has been supposed that the germs of the disease might be disseminated by this current of air. It is quite possible that such might occur. Several of the epidemics of these latter years, however, have not been truly pandemic, and cannot thus be accounted for. On the other hand, as the movement of the air in cyclones in this country is, regarding the cyclone as a whole, from west to east,—the track of the majority of cyclones being in that direction,—one can understand how an air-borne disease, postulating that influenza is air-borne, is unlikely to be spread by the air-currents under such conditions. Apply this reasoning to the facts noted above, and perhaps the supposed rapid spread of influenza on the establishment of anticyclonic conditions may be explained. The air in the cyclonic vortex, drawn chiefly from the atmosphere over the ocean, is moist, and contains none of the contagion ; that of the anticyclone, derived from the higher strata, and thus from distant cyclones, descending, blows gently over the land to the nearest cyclone, and,

being drier, is more able to carry suspended particles with it. Temperature has nothing to do with the problem, except in so far as the different types of weather may modify it.

If reference be made to the "Annals of Influenza" we find that the epidemic of 1510 was preceded by a period of moisture, and followed by remarkable storms; the fact that nothing is recorded of the weather during the attack may indicate that it was dry and uneventful. The epidemic of 1580 was preceded by weather "of a moist, rainy, southerly constitution," and commenced in October, after the setting in of a cold dry wind. In 1758, in September, an outbreak occurred during easterly winds. The spring epidemic of 1782, probably the most widely spread of any, occurred in weather which was "cold, gloomy, humid, with occasional dry fogs." In the other epidemics the meteorological records are confused, and the weather generally reported as being variable. In Creighton's *History of Epidemics of Britain*, vol. 2, it is stated that the epidemic of influenza which occurred in the spring of 1658 was attended by a north wind. It again broke out in 1659, the following note being taken from Willis:—"having had no warm weather before, but a rainy and black week, the sun not appearing for five or six days together, just before the holiday (Easter), when on a sudden that warm weather breaking forth," the outbreak occurred. All these records point to the occurrence of similar phenomena to those noted during the majority of the epidemics of the last six years. I do not mean to assert that such meteorological conditions are by any means indispensable to the spread of influenza in epidemic form, but that they afford favourable facilities for it.

Influenza and the Admissions of the Different Classes of Disease.

In working out the effect of the different epidemics on disease, as represented by the admissions into the Medical Wards, I took, in the first place, the admissions for the weeks during which Influenza was prevalent; and secondly, for a period of 16 weeks, commencing one month after the close of each attack. The interval of a month was necessary to obviate the inclusion of any late cases of Influenza. A period of 12 weeks could only be taken after the epidemic of 1891, owing to the short time which elapsed before the epidemic of 1891–92 set in. The total admissions for these periods were first noted, and then the numbers of cases of different disorders. In the table (Table VII.) following, the figures so obtained have been arranged in columns. The first column contains the total numbers admitted during the periods under consideration. The second column represents the weekly average during the same periods, contrasted in the third column with the mean weekly averages for the year in which the epidemic took place. The last two columns show the percentage of the admissions of different classes of disease to the total numbers during the epidemic weeks, contrasted with the normal percentage of the year. At the head of these last two columns the relative percentages between the total admissions of the year, represented as 100, and the total admissions during the periods under review, are given.

The percentages are added to enable a comparison to be made between the different periods, without the varying element of different admission-rates intruding.

Reference to the first of these tables—that one which deals with the epidemic periods—reveals that in the 9 weeks of the first epidemic, that of 1889–90, every third case admitted suffered from disease of the Respiratory system. The normal proportion was a little over one in every five. Cases of Pneumonia and Pleurisy were very much more numerous than usual, while the number of deaths occurring in hospital were only slightly raised over the mean for the year. Putting it in another way, we find that the number of Respiratory cases admitted in the 9 weeks were increased 47 p.c., of Pneumonia 50 p.c., and of Pleurisy 64 p.c. above the normal. On the other hand, diseases of the Circulatory and Nervous systems were below the normal, the Nervous as

TABLE VII.—*Showing Admissions and Percentages during the Six Epidemics.*

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
1889–90. 9 *Weeks.*					
Total Admissions,	615	68·3	67·8	100·8	100·0
Respiratory System,	204	22·6	15·3	33·1	22·3
Pneumonia,	36	4·0	2·69	5·8	3·96
Pleurisy,	41	4·5	2·8	6·6	4·1
Circulatory System,	41	4·5	5·01	6·6	7·3
Kidney Diseases,	33	3·5	3·4	5·3	5·1
Acute Rheumatism,	17	1·8	1·98	2·7	2·94
Nervous System,	87	9·66	11·3	14·1	16·8
Digestive System,	86	9·55	8·9	13·9	13·0
Mortality,	67	7·4	6·88	10·9	10·1
1891. 13 *Weeks.*					
Total Admissions,	1050	80·7	74·7	107·5	100
Respiratory System,	222	17·0	15·36	21·1	20·9
Pneumonia,	56	4·3	2·71	5·3	3·62
Pleurisy,	50	3·9	3·13	4·7	4·18
Circulatory System,	93	7·1	7·07	8·8	9·4
Kidney Diseases,	54	4·1	3·0	5·1	4·03
Acute Rheumatism,	17	1·03	1·57	1·6	2·09
Nervous System,	171	13·1	13·2	16·2	17·6
Digestive System,	116	8·9	9·0	11·0	12·0
Mortality,	104	8·0	6·96	9·9	9·3
1891–92. 16 *Weeks.*					
Total Admissions,	1219	76·1	72·6	105·0	100·0
Respiratory System,	356	22·2	16·2	29·2	22·3
Pneumonia,	79	4·9	3·63	6·4	5·0
Pleurisy,	64	4·0	2·9	5·2	4·0
Circulatory System,	121	7·5	7·44	9·9	10·2
Kidney Diseases,	42	2·6	3·3	3·4	4·5
Acute Rheumatism,	25	1·5	1·11	2·0	1·56
Nervous System,	160	10·0	11·0	13·1	15·3
Digestive System,	144	9·0	10·2	11·7	14·1
Mortality,	118	7·3	7·03	9·6	9·7

TABLE VII.—*Showing Admissions and Percentages during the Six Epidemics* —continued.

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
1893. 7 *Weeks.*					
Total Admissions,	518	74·0	75·8	97·7	100·0
Respiratory System,	131	18·7	15·5	25·2	20·5
Pneumonia,	34	4·8	3·51	6·5	4·63
Pleurisy,	17	2·4	1·9	3·2	2·58
Circulatory System,	49	7·0	7·69	9·4	10·1
Kidney Diseases,	19	2·7	3·8	3·6	5·07
Acute Rheumatism,	12	1·7	2·05	2·3	2·7
Nervous System,	74	10·5	13·0	14·2	16·8
Digestive System,	73	10·4	10·9	14·0	14·4
Mortality,	54	7·8	8·11	10·4	10·69
1893–94. 16 *Weeks.*					
Total Admissions,	1207	75·4	78·4	96·2	100·0
Respiratory System,	290	19·2	17·5	24·0	22·3
Pneumonia,	69	4·3	3·5	5·7	4·46
Pleurisy,	41	2·5	2·78	3·3	3·5
Circulatory System,	104	6·5	7·3	8·6	9·07
Kidney Diseases,	57	3·5	4·3	4·7	5·4
Acute Rheumatism,	14	0·8	3·4	1·1	4·4
Nervous System,	195	12·2	13·2	16·1	16·8
Digestive System,	184	11·5	10·9	16·0	13·9
Mortality,	124	7·7	7·4	10·2	9·07
1895. 7 *Weeks.*					
Total Admissions,	680	97·1	90·1	108·0	100·0
Respiratory System,	178	25·4	18·6	26·2	20·4
Pneumonia,	42	6·0	3·3	6·2	3·69
Pleurisy,	18	2·5	2·2	2·6	2·5
Circulatory System,	58	8·2	7·63	8·5	8·4
Kidney Diseases,	18	2·5	3·4	2·6	3·5
Acute Rheumatism,	28	4·0	3·2	4·1	3·5
Nervous System,	73	10·4	13·1	10·7	14·5
Digestive System,	98	14·0	13·0	14·4	14·3
Mortality,	73	10·4	8·24	10·7	9·14

much as 15 p.c.; cases of Acute Rheumatism were also less than usual, while diseases of the Kidney and of the Digestive system were very slightly in excess. The weather record for the same period shows it to have been the wettest of the six, and at the same time we may notice that this epidemic was marked by a greater excess of Respiratory disorders than any of the others.

The table for the 13 weeks of 1891 shows that the total Respiratory cases were not nearly so numerous, although the cases of Pneumonia were again much above the average. The total admissions were 7·5 p.c. above the normal for the year, the Respiratory cases 11 p.c., Pneumonia 55 p.c. and Pleurisy 25 p.c. The admissions for diseases of the other systems correspond very closely to those noted in the previous epidemic.

The total admissions for the 16 weeks of the third epidemic, 1891–92, were 5 p.c. above the normal, the mortality slightly below. The Respiratory cases were again much above the mean, 36 p.c., Pneumonia 36 p.c., and Pleurisy 36 p.c.— a curious similarity; while all the other classes investigated were below the average except that of Acute Rheumatism, which was slightly above it.

During the epidemic of 1893, a spring epidemic, the total admissions were 2·3 p.c. below the normal, the Respiratory cases 20 p.c. above, Pneumonia 32 p.c., and Pleurisy 21 p.c. over the mean for the year; but if it be remembered that the epidemic occurred when these diseases are nearly at their lowest for the year, the increase is more marked in reality than the figures show. The numbers of all the other systems were down below the mean.

The outbreak which occurred during the winter of 1893–94, and lasted for 16 weeks, was not characterised by a great increase of Respiratory disorders, only 3 p.c., though the Pneumonia cases admitted were 23 p.c. above the mean. Pleurisy, on the other hand, was below the normal average, as much as 6 p.c. Diseases of the Digestive system were, however, above their average, as much as 6 p.c. The total admissions and cases from other systems were below the normal for the year.

The last epidemic occurred in the spring of 1895. During it the total admissions rose 8 p.c. over the year's mean, the Respiratory cases 35 p.c., Pneumonia 80 p.c., and Pleurisy 12 p.c. The excessive rise in the Pneumonia cases may be readily accounted for by the very severe weather of the period. The mortality was also above the mean, while the other classes were either below or about the normal for the year.

If the figures for the whole 68 weeks be treated in the same manner (Table IX. p. 602), we find the same relation between the cases and the total admissions. Thus the total admissions themselves were 3 p.c. above the average for seven years, cases of Respiratory disease 4·8 p.c. up, compared with the normal percentage of these cases to the total admissions, or, to put it differently, the actual increase in numbers over the normal was 9·1 p.c. The cases of Pneumonia admitted were increased 1·9 p.c. above the normal percentage to admissions, of Pleurisy 0·87 p.c. The actual increase over the normal was 54 p.c. for Pneumonia, the average for 68 weeks being 204 cases, the actual 316, and for Pleurisy 31 p.c., or 231 cases instead of 176. The number of deaths for the same weeks was below the mean if considered in relation to the total admissions, slightly above the actual mean in point of numbers. All the other systems investigated showed a diminution in numbers, the Nervous as much as 10 p.c.

Consideration of the facts adduced above shows that in all the six epidemics the Respiratory system was the one chiefly implicated, while there was a diminution in the cases of disease of other systems, both actually and in relation to the number of total admissions. The mortality in the Medical Wards was little altered.

A very different picture is presented by the figures of the periods following the Influenza epidemics. The tables (Table VIII.) for these periods have been drawn out in exactly the same manner as those relating to the epidemic weeks.

TABLE VIII.—*Showing Admissions and Percentages for the Periods of Sixteen Weeks after the Six Epidemics.*

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
1889–90. 16 *Weeks.*					
Total Admissions,	1083	67·6	67·8	99·9	100·0
Respiratory System,	240	15·0	15·3	22·1	22·3
Pneumonia,	47	2·9	2·69	4·3	3·96
Pleurisy,	47	2·9	2·8	4·3	4·1
Circulatory System,	76	4·7	5·01	7·01	7·3
Kidney Diseases,	64	4·0	3·4	5·4	5·1
Acute Rheumatism,	24	1·5	1·98	2·2	2·94
Nervous System,	196	12·2	11·3	18·0	16·8
Digestive System,	141	8·8	8·9	13·0	13·0
Mortality,	104	6·5	6·88	9·59	10·1
1891. 12 *Weeks.*					
Total Admissions,	827	68·9	73·6	92·5	100·0
Respiratory System,	160	13·3	15·7	19·3	21·6
Pneumonia,	23	1·9	3·17	2·7	4·31
Pleurisy,	24	2·0	3·0	2·9	4·09
Circulatory System,	65	5·4	7·25	7·8	9·8
Kidney Diseases,	29	2·4	3·15	3·4	4·26
Acute Rheumatism,	13	1·08	1·34	1·5	1·8
Nervous System,	141	11·8	12·1	17·0	16·4
Digestive System,	114	9·5	9·6	13·7	12·05
Mortality,	62	5·1	6·99	7·4	9·5
1891–92. 16 *Weeks.*					
Total Admissions,	1148	71·7	72·6	98·8	100·0
Respiratory System,	244	15·2	16·2	21·2	22·3
Pneumonia,	65	4·0	3·63	5·6	5·0
Pleurisy,	38	2·3	2·9	3·3	4·0
Circulatory System,	146	9·1	7·44	12·7	10·2
Kidney Diseases,	63	3·93	3·3	5·49	4·5
Acute Rheumatism,	17	1·06	1·11	1·4	2·7
Nervous System,	173	10·8	11·0	15·0	15·3
Digestive System,	166	10·3	10·2	14·2	14·1
Mortality,	116	7·2	7·03	10·1	9·7
1893. 16 *Weeks.*					
Total Admissions,	1206	75·3	75·8	99·5	100·0
Respiratory System,	210	13·2	15·5	17·4	20·5
Pneumonia,	47	2·92	3·51	3·89	4·63
Pleurisy,	25	1·56	1·9	2·0	2·58
Circulatory System,	134	8·3	7·69	11·1	10·1
Kidney Diseases,	54	3·3	3·8	4·4	5·07
Acute Rheumatism,	28	1·7	2·05	2·3	2·7
Nervous System,	225	14·06	13·0	18·9	16·8
Digestive System,	182	11·3	10·9	15·0	14·4
Mortality,	122	7·6	8·11	10·1	10·69

TABLE VIII.—*Showing Admissions and Percentages for the Periods of Sixteen Weeks after the Six Epidemics*—continued.

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
1893–94. 16 *Weeks.*					
Total Admissions,	1278	79·8	78·4	101·4	100·0
Respiratory System,	277	17·3	17·5	21·6	22·3
Pneumonia,	51	3·1	3·5	3·9	4·46
Pleurisy,	56	3·5	2·78	4·3	3·5
Circulatory System,	130	8·1	7·3	10·1	9·07
Kidney Diseases,	86	5·3	4·3	6·6	5·4
Acute Rheumatism,	58	3·6	3·4	4·5	4·4
Nervous System,	220	13·7	13·2	17·2	16·8
Digestive System,	155	9·7	10·9	12·1	13·9
Mortality,	107	6·7	7·11	8·29	9·07
1895. 16 *Weeks.*					
Total Admissions,	1447	90·4	90·1	100·4	100·0
Respiratory System,	295	18·4	18·6	20·3	20·4
Pneumonia,	54	3·3	3·3	3·7	3·69
Pleurisy,	41	2·5	2·2	2·8	2·5
Circulatory System,	123	7·7	7·63	8·1	8·4
Kidney Diseases,	59	3·7	3·4	4·0	3·5
Acute Rheumatism,	43	2·7	2·2	2·9	3·5
Nervous System,	231	14·4	13·1	15·9	14·5
Digestive System,	212	13·1	13·0	14·6	14·3
Mortality,	141	8·8	8·24	9·7	9·14

During the 16 weeks following the attack of 1889–90, and beginning one month after the attack had ceased, as explained above, the weekly averages show a practically normal admission-rate, a number of Respiratory cases slightly below the normal, although the cases of Pneumonia and Pleurisy were still in slight excess, while more patients were admitted with diseases of the Urinary and Nervous systems than was usual for the year. The excess of Nervous cases was as much as 9 p.c. Comparing the figures for the period of the epidemic with those for that after it, we find that the percentage to the total admissions of the Respiratory cases fell from 33·1 p.c. to 22·1 p.c., the mean for the year being 22·3 p.c.; the cases of Pneumonia and Pleurisy fell from 5·8 p.c. and 6·6 p.c. to 4·3 p.c. in each instance; Circulatory cases rose from 6·6 to 7·01 p.c., Nervous from 14·1 to 18·0 p.c.; while the mortality of the first period was 10·9 p.c. compared with 9·59 p.c. for the second.

Only 12 weeks could be taken at an interval of 4 weeks after the epidemic of 1891, owing to the quick return of the disease. During three weeks the total number admitted fell much below the year's average, 7·5 p.c., and cases belonging to the Respiratory, Circulatory, and Urinary systems were all below normal, those of the Nervous and Digestive above it. The mortality was very markedly below the annual mean. Con-

trasting these figures with those for the corresponding epidemic period, the differences become much more accentuated. For instance, the total admissions were 7·5 p.c. up in the one, 7·5 p.c. down in the other, the corresponding figures for the Respiratory system being 21·1 p.c. and 19·3 p.c., for Pneumonia 5·3 p.c. and 2·7 p.c., Pleurisy 4·7 p.c. and 2·9 p.c., the Nervous system 16·2 p.c. and 17·0 p.c., and for the mortality 9·9 p.c. and 7·4 p.c. The after-effects of this epidemic of Influenza were therefore very slight.

A study of the figures for the 16 weeks after the great epidemic of 1891–92 shows that they correspond very closely to those already given, the only points worthy of mention being that cases of Pneumonia still remained more numerous than usual, the Heart cases were much above the normal, while the Nervous cases were practically normal. Contrasting them with the figures for the epidemic period we find the following:—the total admissions were 5 p.c. above the mean during, and 1·2 p.c. below after, the epidemic, the Respiratory cases 29·2 p.c. and 21·2 p.c., Circulatory 9·9 p.c. and 12·7 p.c., and Nervous 13·1 and 15 p.c., the mortality 9·6 p.c. during, and 10·1 p.c. after. The Circulatory system seems, therefore, to have suffered the most in this instance.

The Circulatory and Nervous systems were most affected after the next epidemic also, the other figures calling for little notice. Comparing them as before with the figures for the epidemic weeks, the usual differences are well brought out again. The total admissions were below the normal during each period; the Respiratory cases 25·2 p.c. and 17·4 p.c., Pneumonia 6·5 p.c. and 3·89 p.c., Pleurisy 3·2 p.c. and 2·0 p.c., Circulatory cases 9·4 p.c. and 12·1 p.c., Nervous cases 14·2 p.c. and 18·9 p.c., while the mortality was slightly below the mean in both periods. The epidemic of 1893 was followed, therefore, by an increase in Cardiac and Nervous affections, the latter very markedly.

The outbreak of 1893–94 is peculiar in that the total admissions during the epidemic were below the average for the year, and for the period after the attack above it, the figures being 96·2 p.c. and 101·4 p.c. respectively. The figures for the different classes of disease do not present much variation from those of the other post-epidemic periods, both the Circulatory and Nervous systems again showing an increased number of admissions.

The last epidemic, that of 1895, was followed by the same conditions, except that the Circulatory system did not suffer much, while the death-rate kept up above the normal. Perhaps the most striking point was the difference between the numbers of Nervous cases admitted during and after the epidemic: 10·7 p.c. to the total admissions during, they rose to 15·9 p.c. after the attack; or, to put it in a different way, the increase in the actual numbers after the outbreak was 10 p.c., the decrease before 20·6 p.c.

The next table (Table IX.) shows the same figures considered in bulk,—that is, for the total period in which Influenza was epidemic, or 68 weeks, and for the 92 weeks which followed them, beginning 4 weeks after the close of the epidemics. The means taken, with which the numbers were compared, are for the seven years from October 1888 to October 1895. The total admissions of all cases into the Medical Wards were 3 p.c. above the mean during the epidemic periods, 0·6 p.c. above it for the succeeding weeks.

TABLE IX.—*Showing the Admissions during the Sixty-Eight Weeks in which Influenza was Epidemic, and their Percentage to the Total Admissions.*

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
Total Admissions,	5289	77·7	75·5	103·0	100
Respiratory System,	1381	20·3	15·96	26·1	21·3
Pneumonia,	316	4·6	3·05	5·9	4·04
Pleurisy,	231	3·4	2·58	4·3	3·43
Circulatory System,	466	6·8	6·87	8·8	9·01
Kidney Diseases,	223	3·2	3·44	4·2	4·5
Acute Rheumatism,	113	1·6	2·04	2·1	2·7
Nervous System,	760	11·19	12·35	14·3	16·34
Digestive System,	701	10·3	10·21	13·2	13·41
Mortality,	540	7·9	7·24	10·2	9·59

Similar Table to show the Admissions, &c. for the Periods of Sixteen Weeks, beginning one Month after each Epidemic, or for Ninety-Two Weeks.

	Totals.	Weekly.	Normal Weekly.	Percentage to Admissions.	Normal Percentage.
Total Admissions,	6989	75·9	75·5	100·6	100
Respiratory System,	1426	15·5	15·96	20·3	21·3
Pneumonia,	273	2·9	3·05	3·9	4·04
Pleurisy,	231	2·5	2·58	3·3	3·43
Circulatory System,	674	7·3	6·87	9·63	9·01
Kidney Diseases,	355	3·85	3·44	5·08	4·5
Acute Rheumatism,	183	2·0	2·04	2·6	2·7
Nervous System,	1186	12·9	12·35	16·9	16·34
Digestive System,	970	10·5	10·21	13·8	13·41
Mortality,	646	7·0	7·24	9·2	9·59

If we take into account, in the first place, only the percentage figures to the total admissions, we find that the Respiratory cases admitted during the epidemic weeks constituted 26·1 p.c. of the whole, after the epidemics only 20·3 p.c., the normal being 21·3 p.c. Cases of Pneumonia were 5·9 p.c. of the total during, 3·9 p.c. after the epidemics, the normal mean being 4·04 p.c. The similar figures for Pleurisy were 4·3 p.c. during, 3·3 p.c. after, with a mean of 3·43 p.c. Cases of Heart disease constituted 8·8 p.c. during, 9·63 p.c. after the attacks, the normal being 9·01 p.c. Kidney diseases varied only slightly: 4·2 p.c. of the whole during the attacks, they formed 5·08 p.c. after them. Cases of Acute Rheumatism were below the normal in both instances. The Nervous system seemed to be less affected during the outbreaks than more affected after them, the figures being 14·3 p.c. before, 16·9 p.c. after, and the normal 16·34 p.c. The

corresponding figures for the Digestive system were 13·2 p.c. before, 13·8 p.c. after, with a normal of 13·41 p.c. The death-rate during the epidemics was 10·2 p.c., after them 9·2 p.c., the normal being 9·59 p.c.

From a consideration of these facts we must conclude that Influenza attacks the respiratory organs at the time, as of course is well known, while it does not seem to cause serious affections of the other systems, especially of the circulatory and nervous, until some time later. This fact is of considerable importance; for by the time these secondary results appear, the patient is generally out of the doctor's hands; and as they may appear very insidiously, they may not be properly treated until the disease has obtained a strong hold on the part affected.

Previous Epidemics of Influenza from 1848.

I have thought that it would be interesting and of value to investigate in a precisely similar manner the previous epidemics of Influenza recorded in the Infirmary books. Unfortunately the books for the period before 1838 were lost at the time of the opening of the present Infirmary buildings. Only the four epidemics which have occurred since 1848 could be considered. A relic of the past, however, exists in the form of a small register for 1782, in which an epidemic of Influenza can be clearly recognised.

Table showing the Weekly Admissions and the Percentages to Total Admissions for the Epidemics from 1848 *to* 1891.

	Year	1848–49. 23 Weeks.	1851. 18 Weeks.	1855. 18 Weeks.	1857–58. 22 Weeks.	1891–92. 23 Weeks.
Totals,		802	724	614	657	1724
Respiratory,	Weekly,	7·73	10·6	10·94	8·36	19·6
	Per cent.,	22·18	26·3	32·2	28·0	26·2
Pneumonia,	Weekly,	1·52	1·72	1·16	1·18	4·1
	Per cent.,	4·36	4·28	3·42	3·94	5·5
Pleurisy,	Weekly,	0·87	0·68	0·83	0·86	3·7
	Per cent.,	2·49	1·51	2·44	2·87	5·0
Cardiac,	Weekly,	0·65	1·2	1·72	2·36	6·9
	Per cent.,	1·87	2·02	5·04	7·88	9·2
Kidney,	Weekly,	1·21	1·06	1·84	1·22	2·5
	Per cent.,	3·49	2·62	5·37	4·1	3·4
Rheumatism,	Weekly,	0·69	1·88	0·44	1·0	1·3
	Per cent.,	1·99	4·69	1·3	3·34	1·8
Nervous,	Weekly,	2·82	4·7	3·44	3·91	10·7
	Per cent.,	8·14	11·7	10·1	13·1	14·3
Digestive,	Weekly,	5·04	3·5	2·61	2·4	8·9
	Per cent.,	14·46	8·97	7·65	8·06	11·8
Influenza,	Weekly,	5·21	1·06	0·5	0·36	8·7
	Per cent.,	14·83	2·62	1·46	1·23	11·7

As a short and clear method of presenting the facts about these epidemics, I have drawn up charts which graphically depict their course. A chart for the epidemic of 1891–92 has been added for comparison. The charts explain themselves, the upper parts representing the actual weekly numbers, the lower the percentages to the total admissions into the Medical Wards. The upper parts are not directly comparable, owing to the variations in the number of total admissions; the lower, as percentages of these total admissions, correspond exactly to one another (Charts II. to VI.).

The epidemic of 1848–49 was the most severe of any of those which I have recorded: as many as 14·83 p.c. of the total admissions for 23 weeks were due to this disease. It is interesting to note that in the Infirmary books it is termed "Fever Epidemic"; only in one instance is a case entered as Influenza. At the height of the attack as many as 16 cases were admitted in one week, giving a percentage of 39·2 p.c. In the figures for this epidemic and for the succeeding ones up to 1858 all fever cases were subtracted from the total admissions into the Medical Wards, as in those days infectious diseases were classed with the other medical cases. The most striking point observable in the chart which has been drawn out for this attack is the large number of patients admitted with Digestive disorders,—14·46 p.c. of the total number,—when compared with the numbers admitted during the other epidemics. It may be also observed that the increase corresponds with the height of the epidemic. Although the attack of Influenza in 1848–49 occurred during the winter months, the Respiratory system was not much affected, if we except cases of Pneumonia, which were in excess during the earlier part. Cardiac affections were very small in number—only 0·65 per week.

The epidemic of 1851, which lasted 18 weeks, was a spring attack, and chiefly remarkable for the large proportion of cases of Acute Rheumatism admitted,—1·88 per week, or 4·69 p.c. of the total number. The percentage for the last seven years was, as we have seen, 2·7 p.c., or a little more than half. The Respiratory cases also showed an increase. Nervous and Digestive cases were few in number.

Although the epidemic which occurred in the beginning of 1855 was very slightly marked in Edinburgh, so far, at any rate, as the admission of actual cases of Influenza was concerned, the percentage of Respiratory cases almost equalled that of the epidemic of 1889–90. In 1889-90 the percentage was 33·1 p.c.: in 1855, 32·2 p.c. Cardiac disease showed an advance on the previous attacks, while the number of Kidney affections were much above normal.

The attack of Influenza which occurred during the winter months of 1857–58 hardly merits the name of Epidemic, but the number of Respiratory cases increased coincidently with the admission of a few cases of Influenza,—a remark which also applies to the admissions of Pneumonia. Only 8 cases of Influenza were recorded at this time. Nervous cases show an increase at the time of the epidemic.*

* The weather conditions which preceded and followed these four epidemics do not correspond exactly

A similar chart was constructed for the epidemic of 1891–92, as the most representative of the later outbreaks, the figures in the upper part being represented half the scale of the other four. The percentages for the five epidemics are of course exactly comparable. A glance at these charts shows that Influenza has not changed its character or its ways from 1848 to the present time, and that the popular idea that the results as at present experienced are much worse than they ever were in the good old days when small-pox killed its thousands, and anti-diphtheritic toxin was unheard of, is not borne out by the facts presented to you.

Description of the Large Chart (Chart I.).

The first chart represents in a graphic form all the data from which the foregoing deductions were made. Each division represents a week, the years are separated by red lines, and the quarters by similar but thinner lines. By an oversight, which was not discovered until too late, two weeks were omitted in the chart for the last quarter of 1889; the numbers for these weeks have been ignored in drawing out the chart, but in no case were they of any unusual significance. The first red line represents the actual number of cases of Respiratory disease admitted during each week, each division corresponding to one admission.

The curve immediately below is a representation of the respiratory cases, "Bloxamed" to fives, *i.e.*, the mean of each successive five weeks is entered for the third or middle week of the period, above 15 being shaded in red, below it in blue.

The actual number of cases of Influenza which occurred in the Infirmary are shown, per week, by dark blue squares—each square, one case.

Immediately below, blue shading indicates the cases of Influenza in the Post Office —each square, two cases.

As to the type of weather, blue shading of a square represents a week in which anti-cyclones were prevalent; red, one under cyclonic conditions.

The temperature is shown in the following manner. Each square shaded blue represents a week in which the maximum did not reach 60°; shaded red, the maximum exceeded that point. Solid blue squares indicate a minimum during the week of below

to those found in the later. I have to thank Mr Mossman for the data from which the following table has been constructed:—

Period.	Type. Cyclonic.	Anti-Cyclonic.	Mean Temperature.	Mean Rainfall.
24 weeks before the four epidemics.	16	8	45·68	·31
First 8 weeks of epidemics.	6	2	41·59	·47
47 weeks during epidemics.	29	18	42·72	·45
Last 8 weeks of epidemics.	6	2	46·37	·39
16 weeks after epidemics.	6	10	46·25	·37

But it must be noted that the epidemic of 1848–49 began during anti-cyclonic conditions, and when north and east winds were unduly prevalent; that of 1851 commenced during cyclonic weather of not a pronounced type, with a small rainfall; that of 1855 during cyclonic weather, in which north winds predominated; and the epidemic of 1857–58 commenced immediately after or during the close of a very marked anti-cyclone of two weeks' duration.

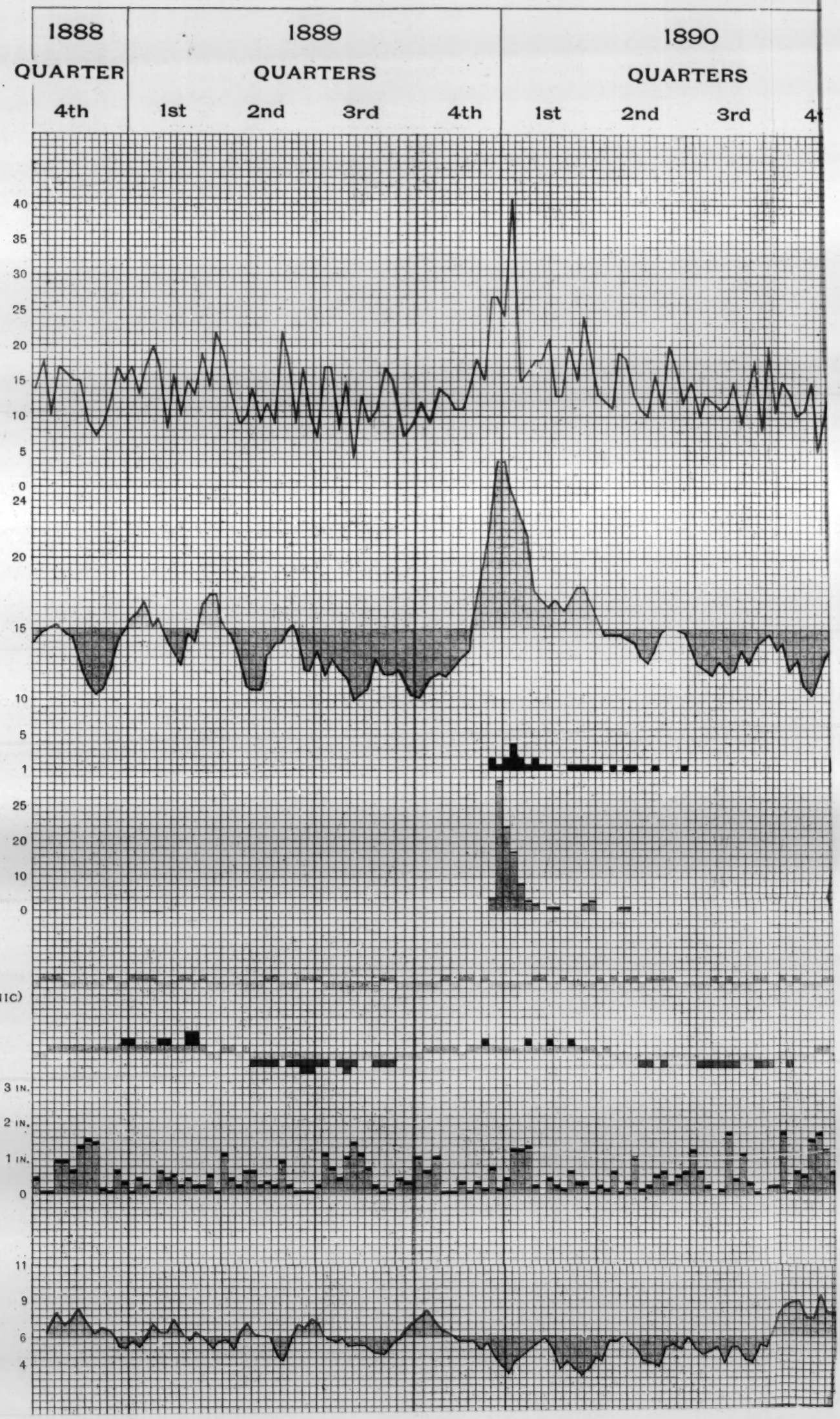
20°, two represent a minimum of below 10°, three of below zero. Similarly, solid red squares show a maximum over 70°, two, of over 80°, and three, of over 90°.

The rainfall is graphically shown by blue shading, each square = 0·2 inches. The admissions of Cardiac, Rheumatic, Kidney, Nervous, and of the total numbers have been treated in averages of fives, and are all drawn to the same scale except those of Kidney disease and of the total admissions—in the first, 5 squares go to one case; in the second, 1 square represents one admission; in the others, 2 squares represent the admission of one case.

The number of deaths is similarly shown. In all these curves red shading corresponds to an admission over the average of the seven years, blue shading to one below it.

CHART I.—THE WEEKLY

with the Weekly Rainfa



ACTUAL NUMBERS OF PATIENTS ADMITTED WITH RESPIRATORY DISORDERS.

THE SAME IN AVERAGES OF FIVE WEEKS.

ACTUAL NUMBERS OF PATIENTS ADMITTED WITH INFLUENZA.

ACTUAL NUMBERS OF INFLUENZA CASES AMONG HE POST-OFFICE OFFICIALS IN EDINBURGH.

WEATHER (RED—CYCLONIC) (BLUE—ANTI-CYCLONIC)

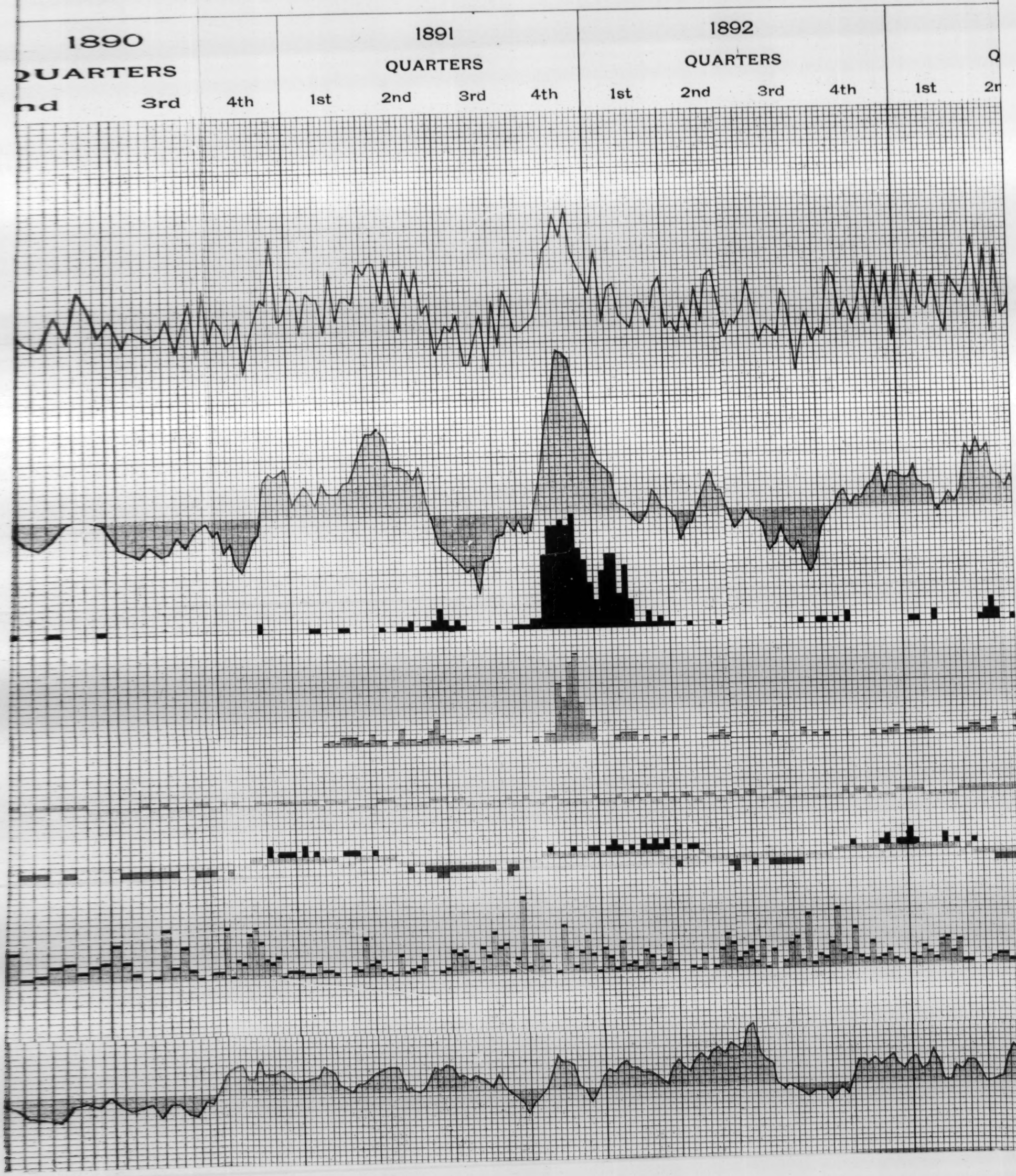
TEMPERATURE.

WEEKLY RAINFALL.

THE NUMBERS OF RT CASES ADMITTED, IN AVERAGES OF FIVES.

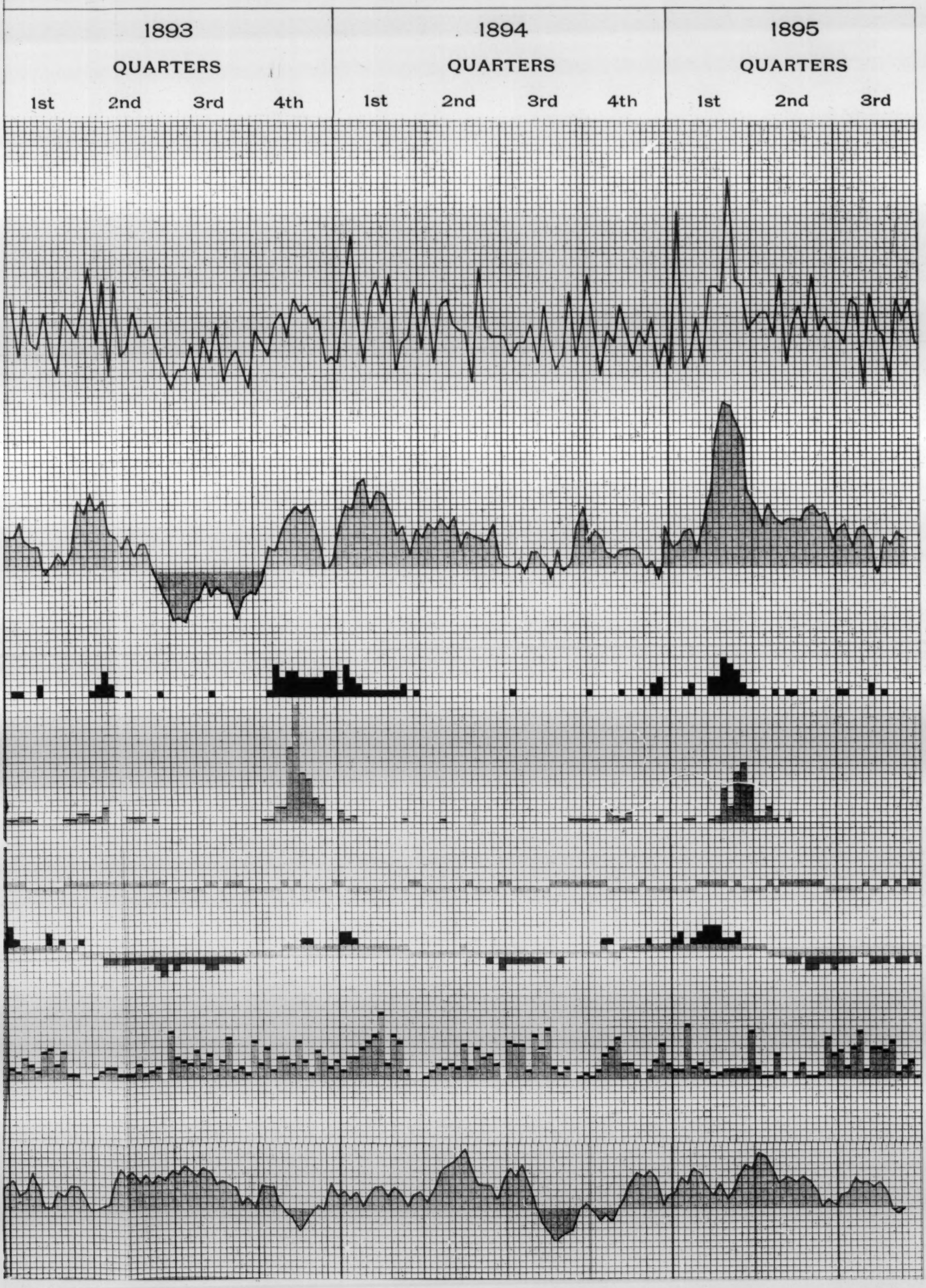
E WEEKLY ADMISSIONS INTO THE MEDICAL WARDS OF THE R

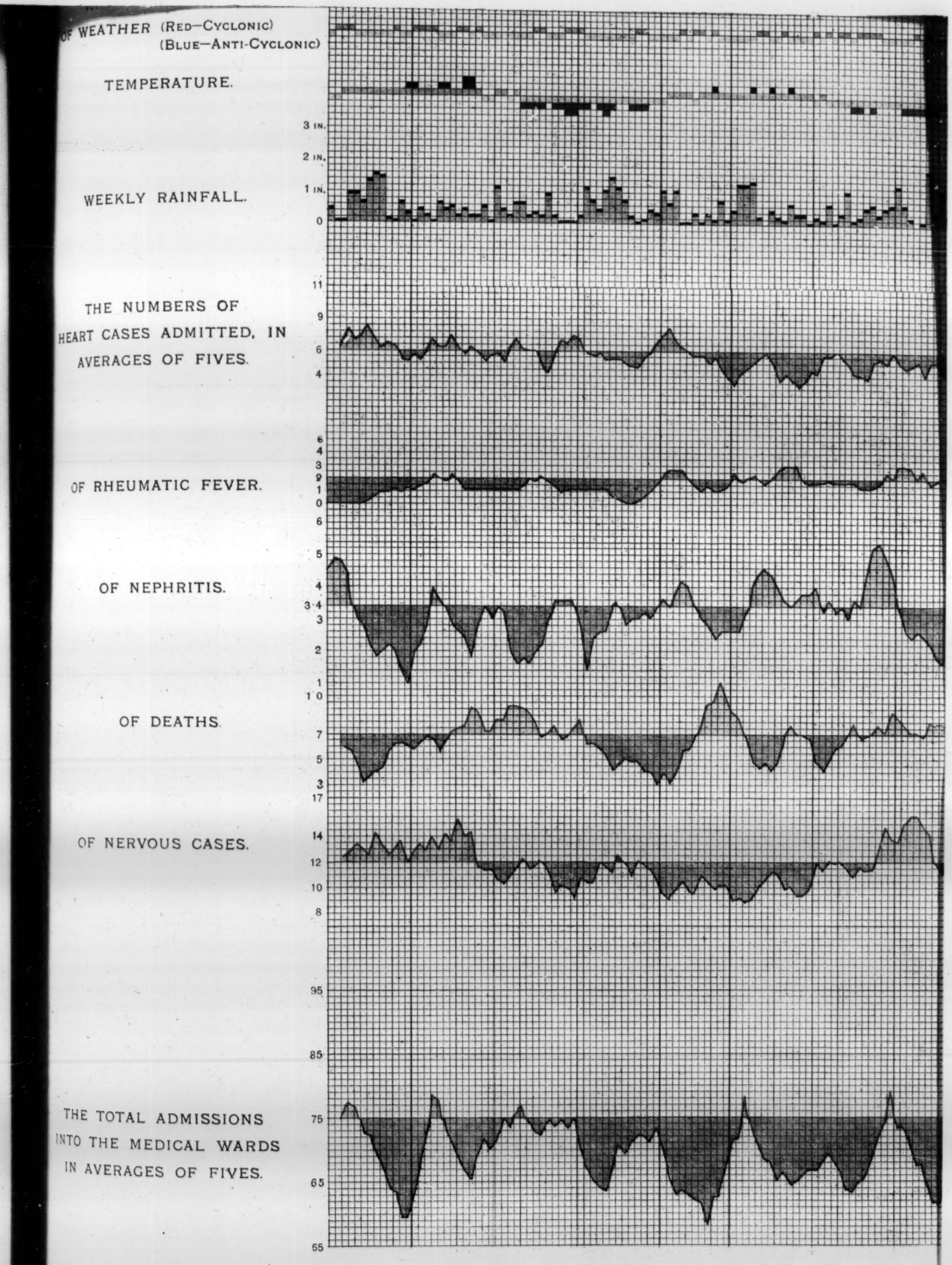
Weekly Rainfall, Temperature, and Type of Weather for Seven Years from October 1st.,



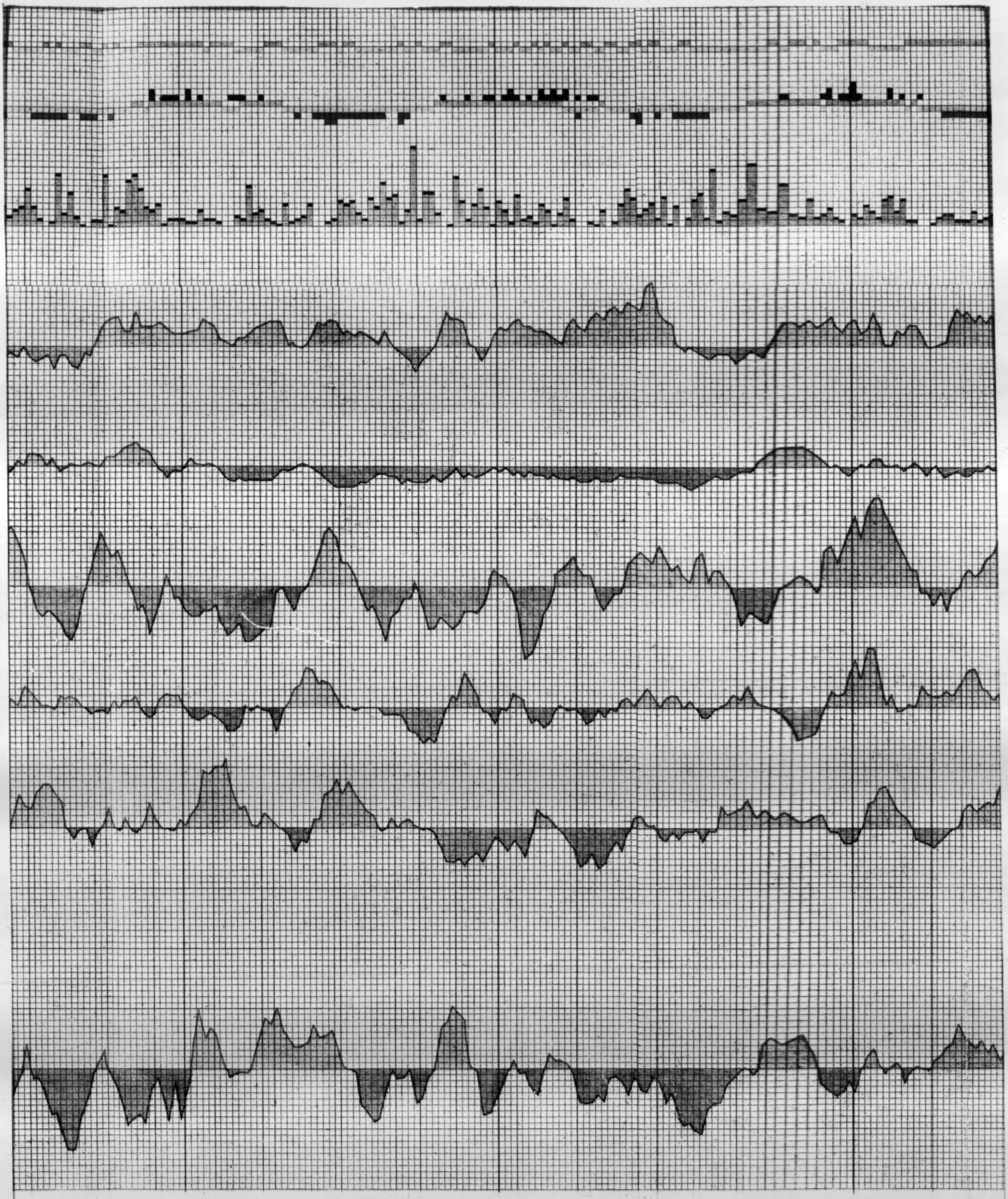
THE ROYAL INFIRMARY, EDINBURGH,

)ctober 1st., 1888, to September 30th, 1895.

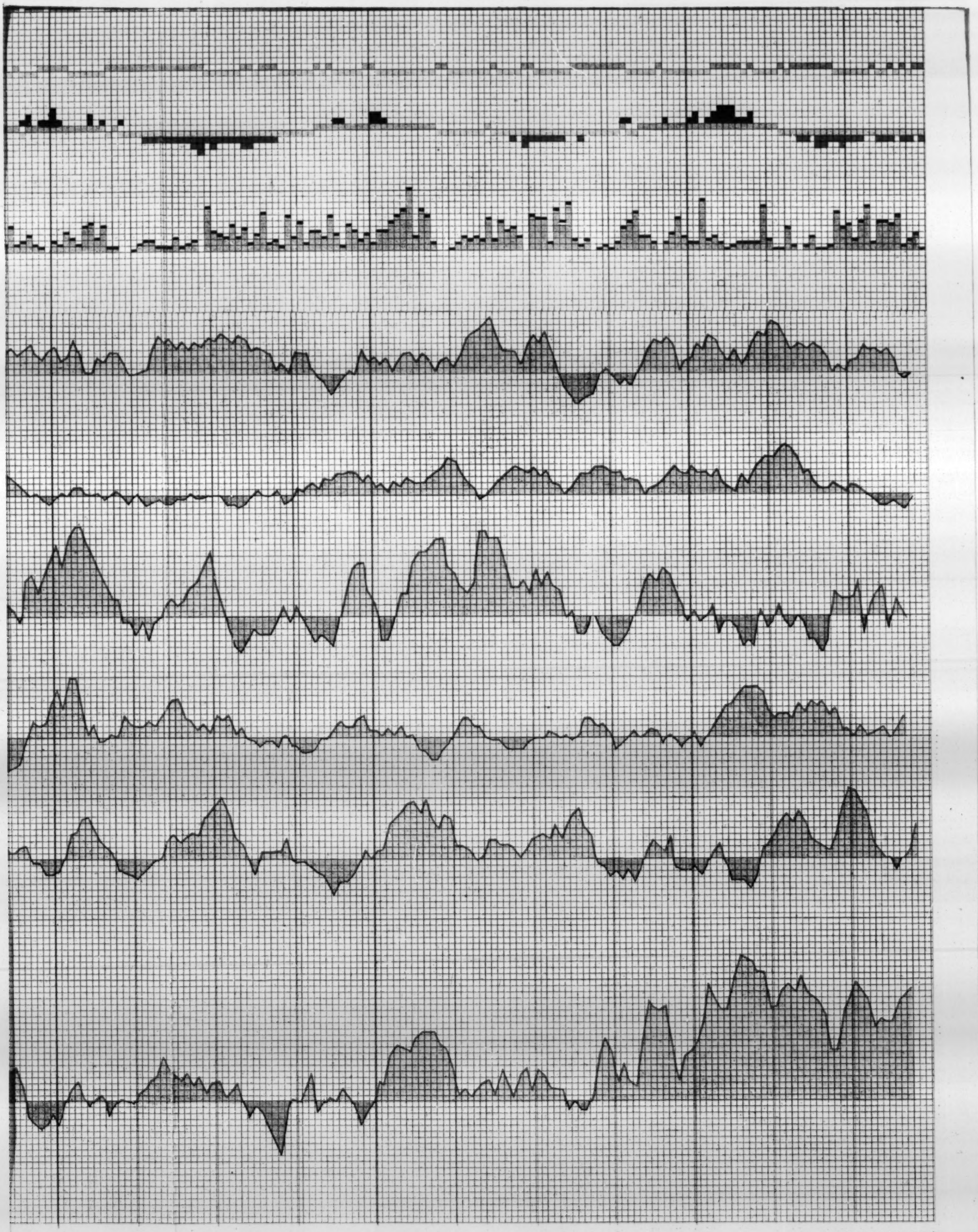




NOTE.—Red shading signifies numbers above the weekly mean; b
One solid red square added represents a rise above 70°; two,
All the figures for admissions, save in the first Respirat



mean; blue, below it. In Temperature record, squares shaded red represent weeks in which the maximum thermometer rose a
'0°; two, a rise above 80°; and three, above 90° Fahr. Similarly, one solid blue square represents a fall below 20°; two, a fal
Respiratory and the two Influenza curves, are represented as successive means of five weeks.



A. RITCHIE & SON, EDIN.

timum thermometer rose above 60° Fahr.; squares shaded blue, weeks in which it did not rise above 60° Fahr.
fall below 20°; two, a fall below 10°; and three, below 0° Fahr.

Chart II.—Epidemic of Influenza in the Winter of 1848-1849.

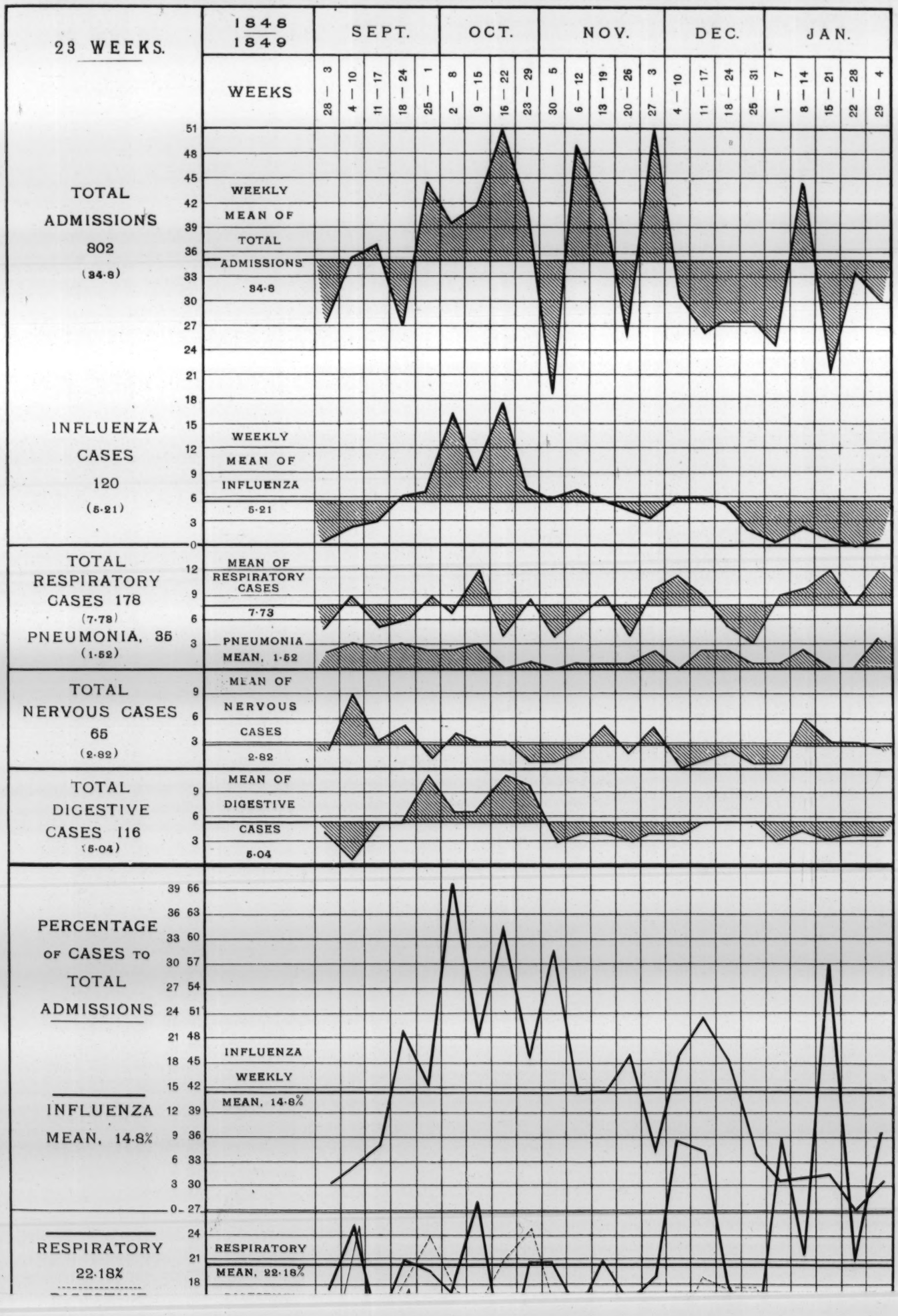
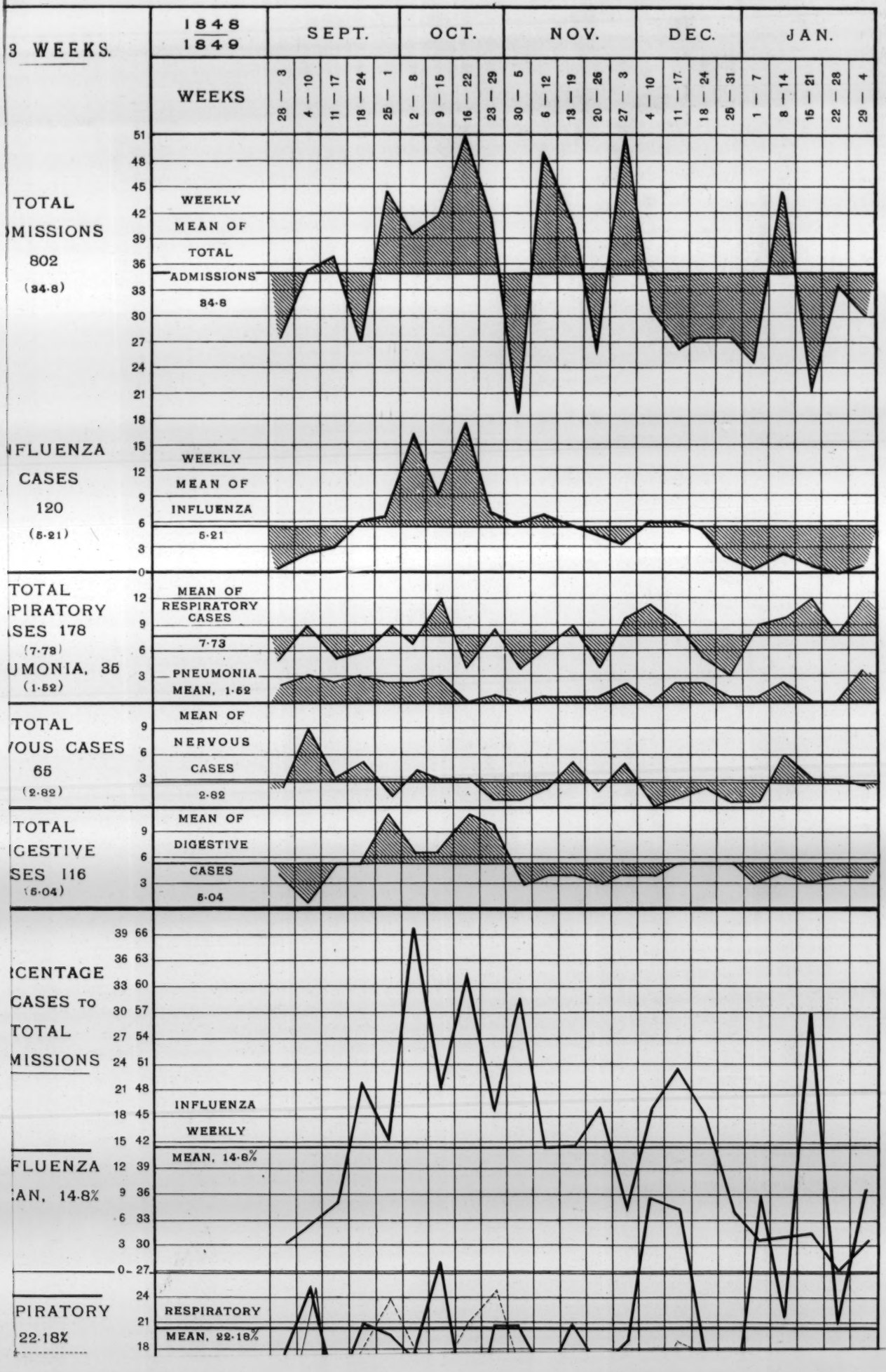


CHART II.—EPIDEMIC OF INFLUENZA IN THE WINTER OF 1848-1849.



TOTAL ADMISSIONS 802 (34·8)

48 45 42 39 36 33 30 27 24 21 18 15 12 9 6 3 0

WEEKLY MEAN OF TOTAL ADMISSIONS 34·8

INFLUENZA CASES 120 (5·21)

WEEKLY MEAN OF INFLUENZA 5·21

TOTAL RESPIRATORY CASES 178 (7·73)

PNEUMONIA, 35 (1·52)

12 9 6 3

MEAN OF RESPIRATORY CASES 7·73

PNEUMONIA MEAN, 1·52

TOTAL NERVOUS CASES 65 (2·82)

9 6 3

MEAN OF NERVOUS CASES 2·82

TOTAL DIGESTIVE CASES 116 (5·04)

9 6 3

MEAN OF DIGESTIVE CASES 5·04

PERCENTAGE OF CASES TO TOTAL ADMISSIONS

39 36 33 30 27 24 21 18 15 12 9 6 3 0

66 63 60 57 54 51 48 45 42 39 36 33 30 27

INFLUENZA MEAN, 14·8%

INFLUENZA WEEKLY MEAN, 14·8%

RESPIRATORY 22·18%

DIGESTIVE 14·4%

NERVOUS CASES MEAN, 8·14%

24 21 18 15 12 9 6 3

RESPIRATORY MEAN, 22·18%

DIGESTIVE MEAN, 14·4%

NERVOUS MEAN, 8·14%

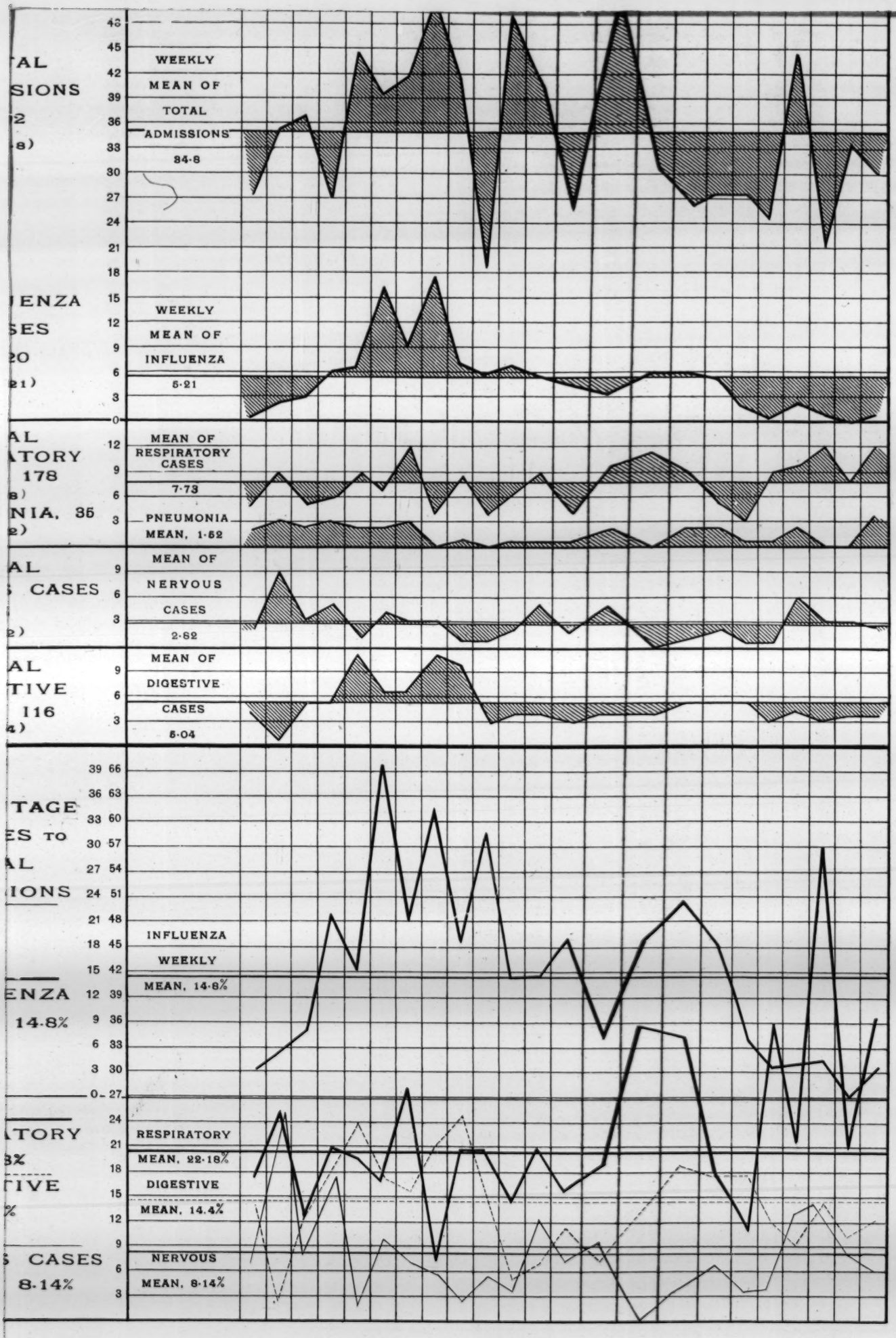
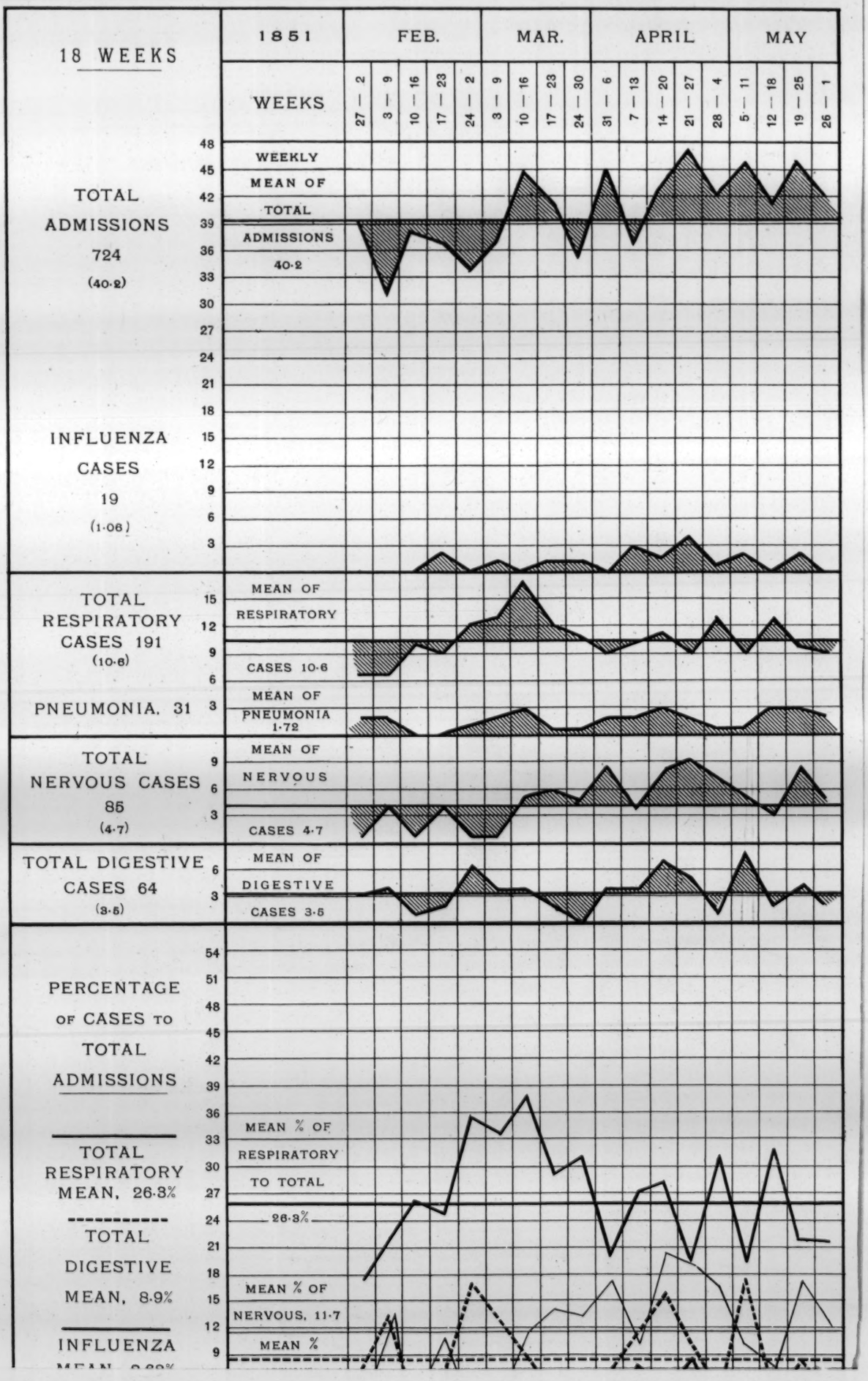
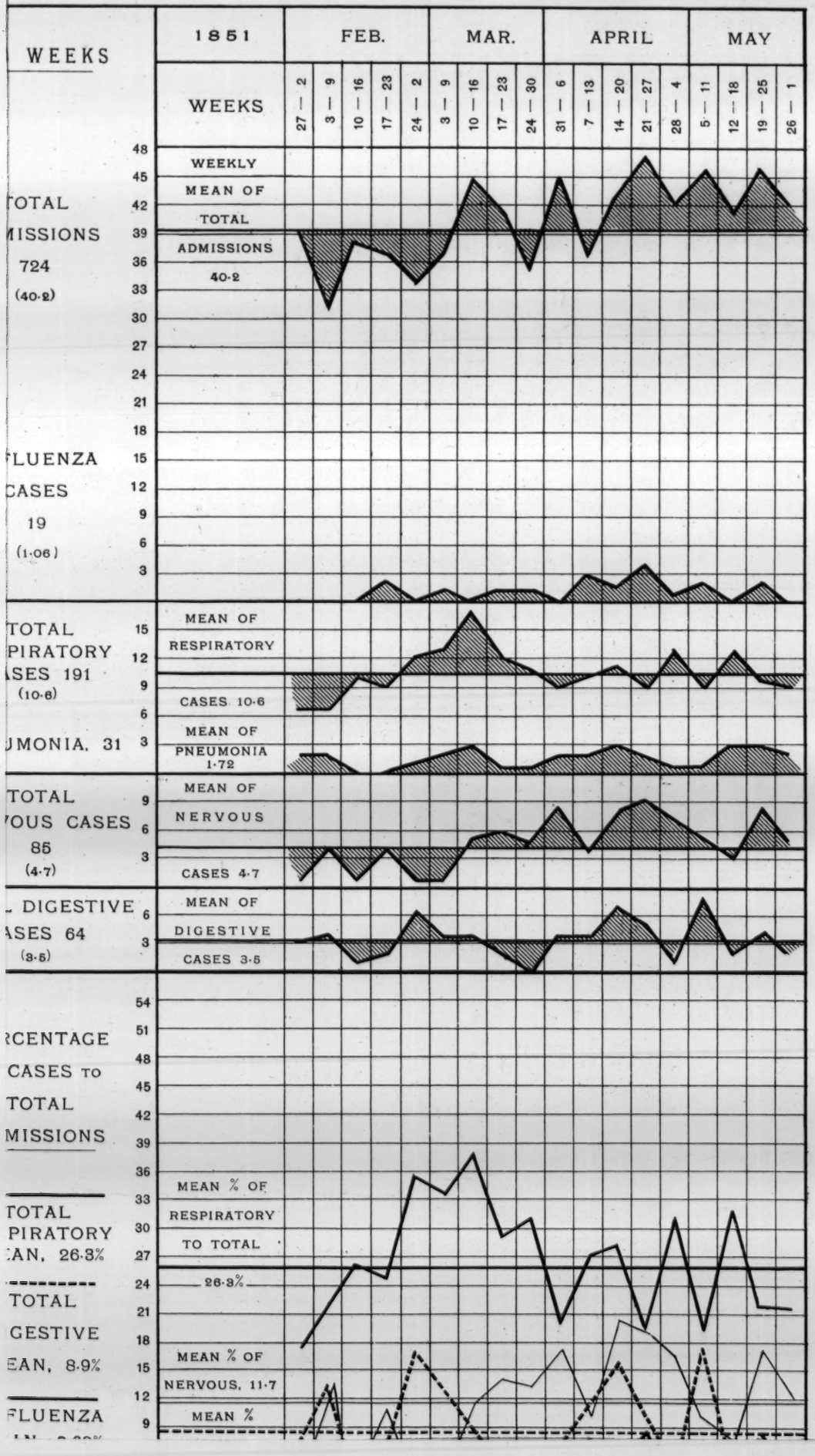
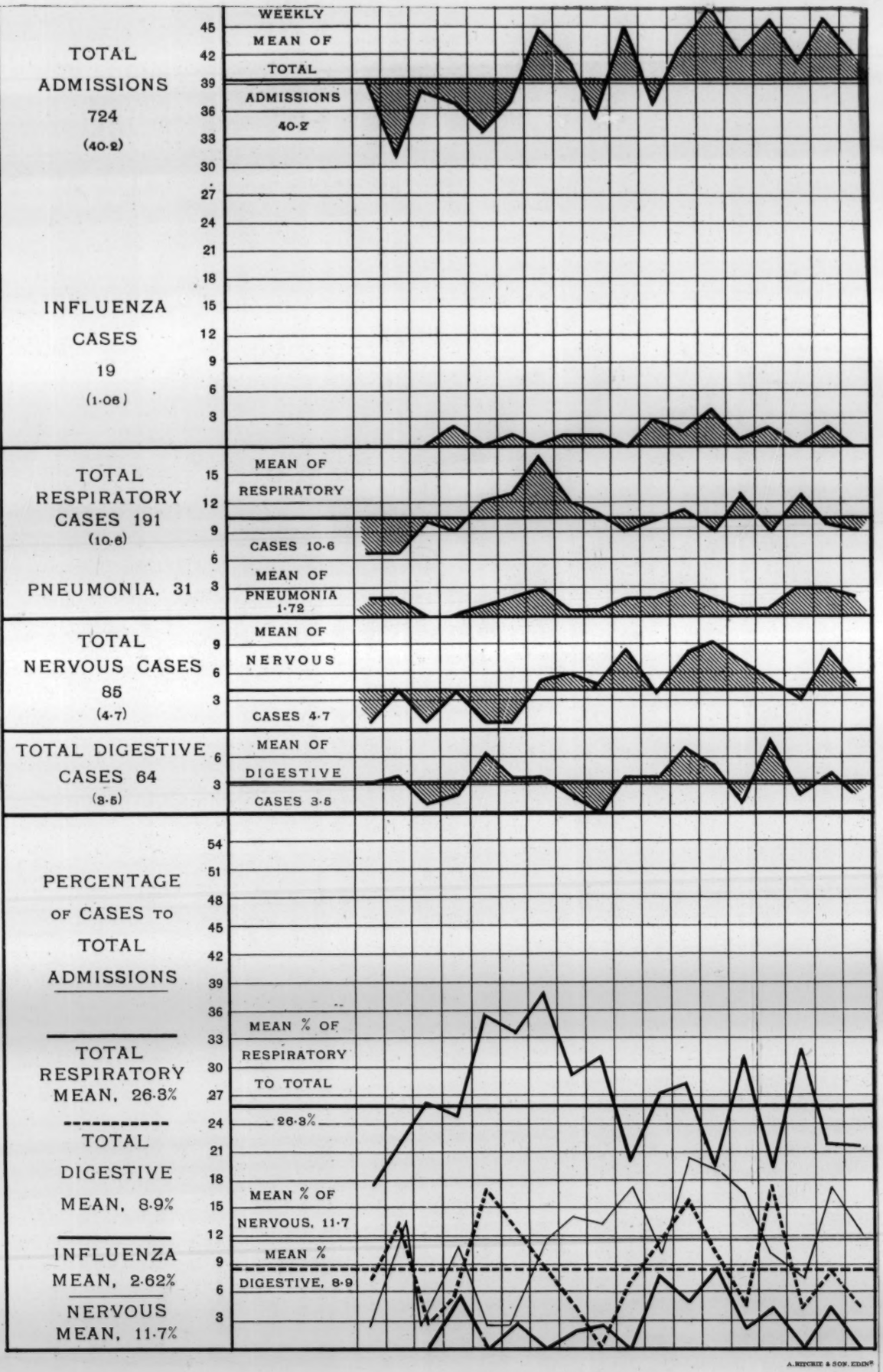

WEEKLY
MEAN OF
TOTAL
ADMISSIONS
34·8
WEEKLY
MEAN OF
INFLUENZA
5·21
MEAN OF
RESPIRATORY
CASES
7·73
PNEUMONIA
MEAN, 1·52
MEAN OF
NERVOUS
CASES
2·82
MEAN OF
DIGESTIVE
CASES
5·04
INFLUENZA
WEEKLY
MEAN, 14·8%
RESPIRATORY
MEAN, 22·18%
DIGESTIVE
MEAN, 14·4%
NERVOUS
MEAN, 8·14%

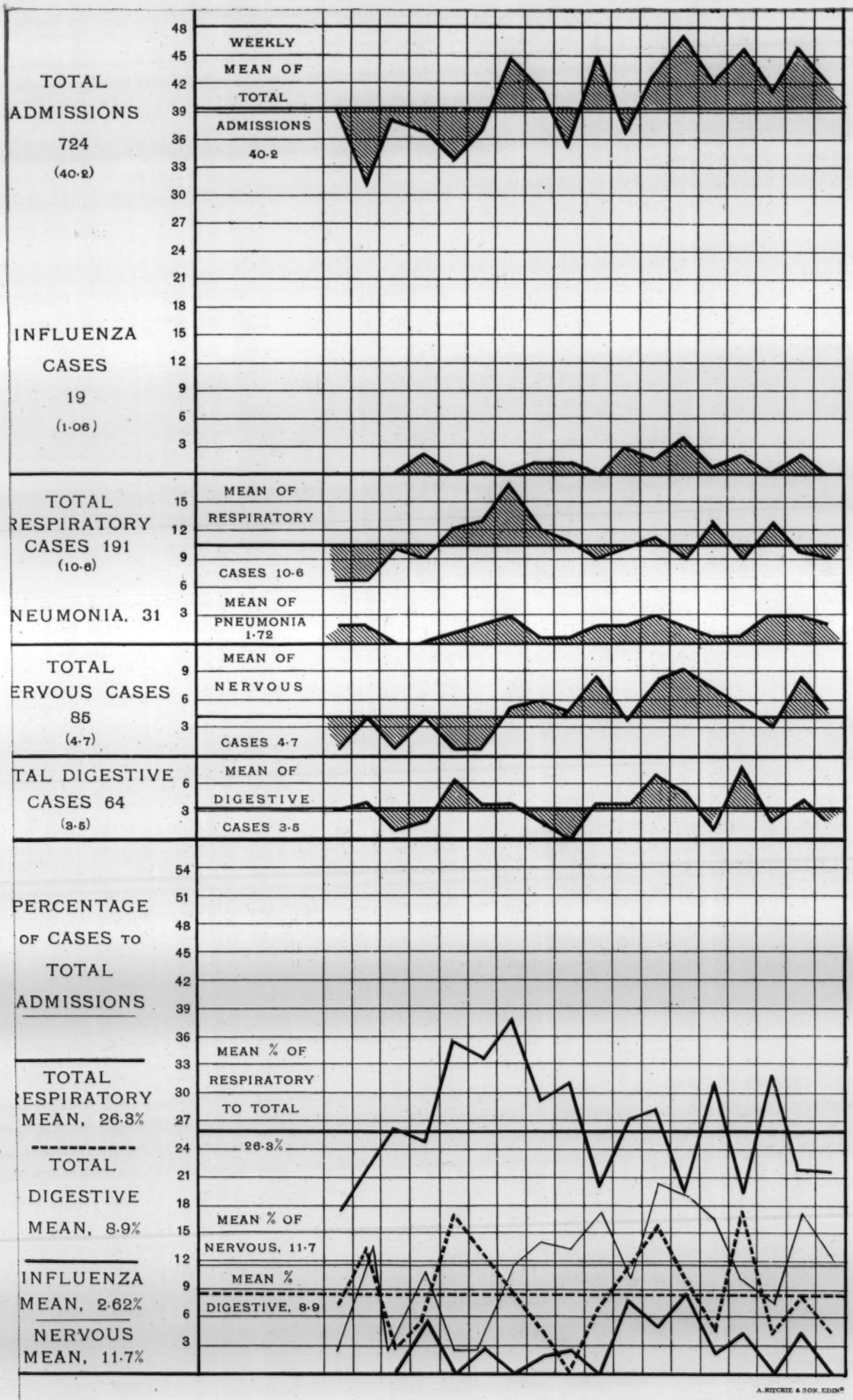
Chart III.—Epidemic of Influenza in the Early Spring of 1851.



RT III.—EPIDEMIC OF INFLUENZA IN THE EARLY SPRING OF 1851.




TOTAL ADMISSIONS 724 (40·2)
INFLUENZA CASES 19 (1·06)
WEEKLY MEAN OF TOTAL ADMISSIONS 40·2
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
TOTAL RESPIRATORY CASES 191 (10·6)
PNEUMONIA, 31
MEAN OF RESPIRATORY CASES 10·6
MEAN OF PNEUMONIA 1·72
15
12
9
6
3
TOTAL NERVOUS CASES 85 (4·7)
MEAN OF NERVOUS CASES 4·7
9
6
3
TOTAL DIGESTIVE CASES 64 (3·5)
MEAN OF DIGESTIVE CASES 3·5
6
3
PERCENTAGE OF CASES TO TOTAL ADMISSIONS
TOTAL RESPIRATORY MEAN, 26·3%
TOTAL DIGESTIVE MEAN, 8·9%
INFLUENZA MEAN, 2·62%
NERVOUS MEAN, 11·7%
MEAN % OF RESPIRATORY TO TOTAL
26·3%
MEAN % OF NERVOUS, 11·7
MEAN % DIGESTIVE, 8·9
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3



A. RITCHIE & SON, EDIN.R

Chart IV.—Epidemic of Influenza in the beginning of 1855.

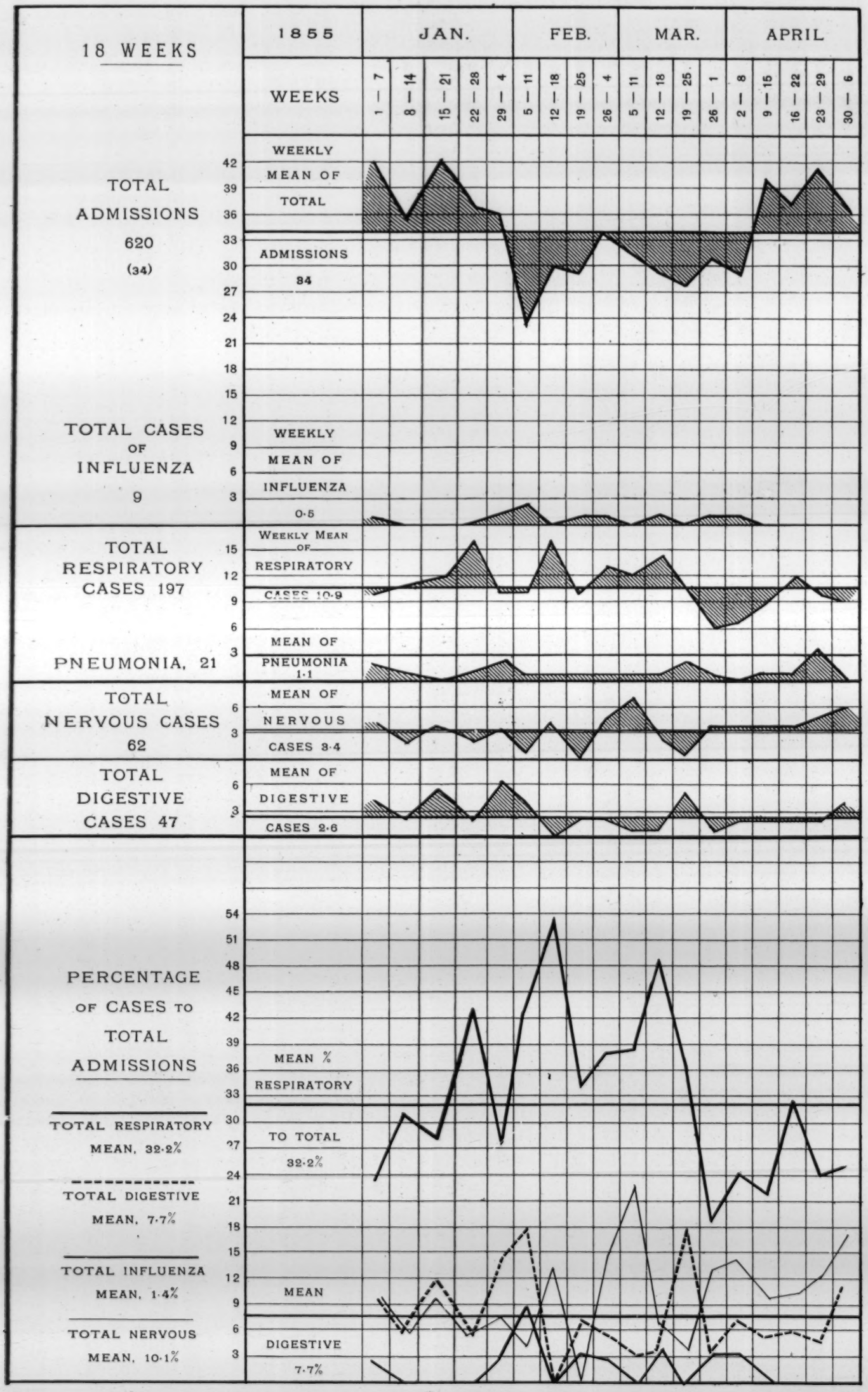
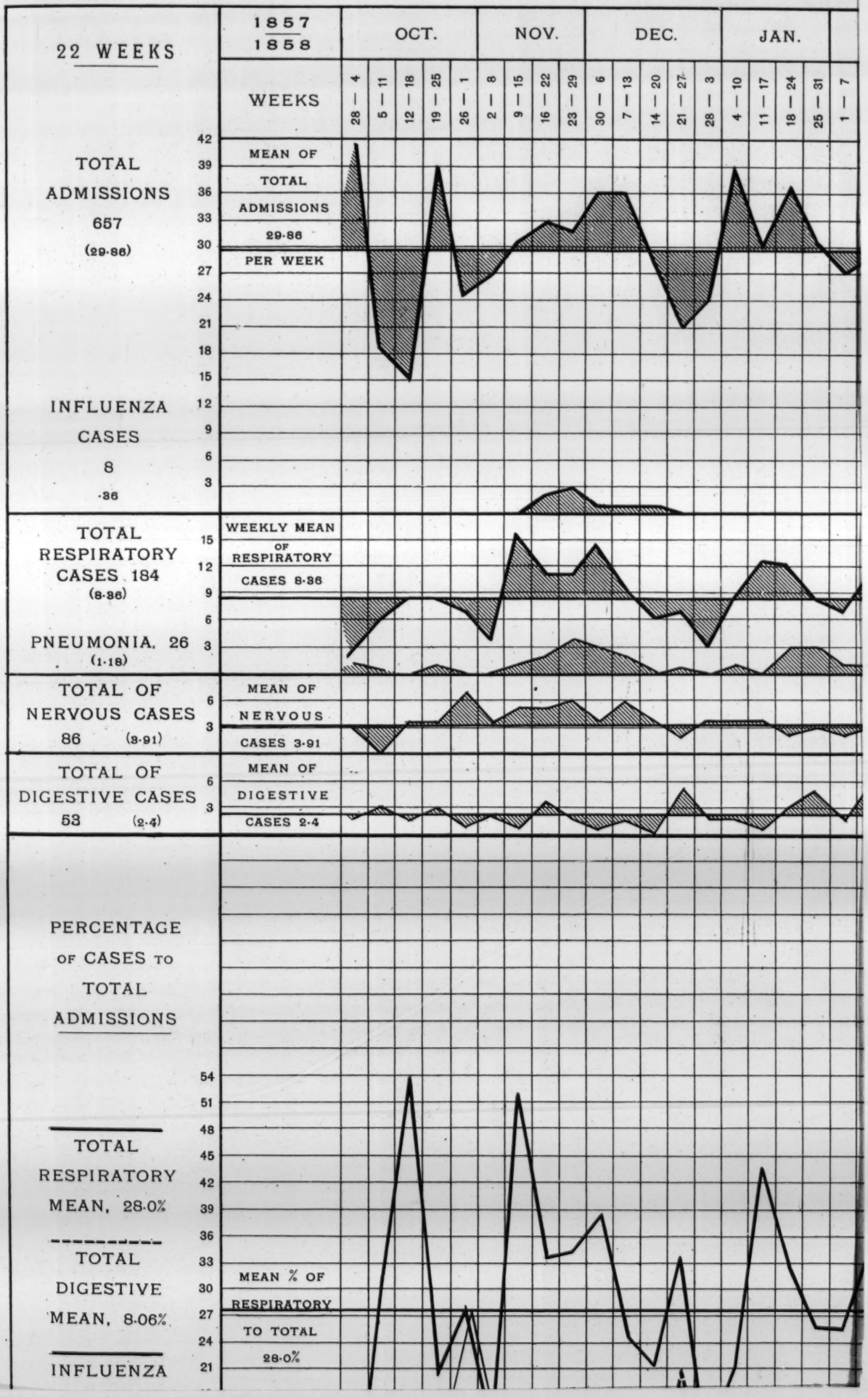
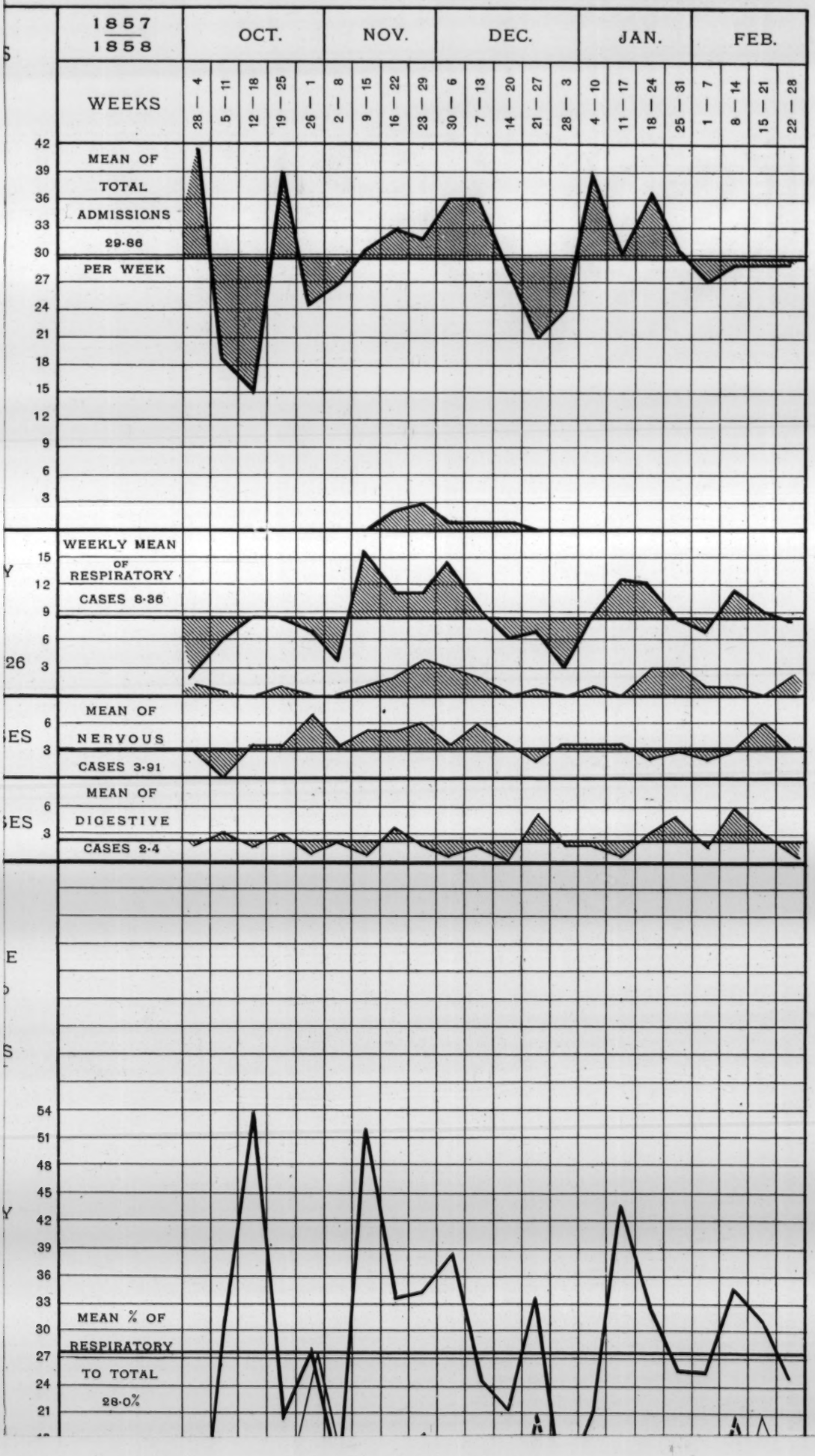


CHART V.—EPIDEMIC OF INFLUENZA IN THE WINTER OF 1857-1



Epidemic of Influenza in the Winter of 1857-1858.



TOTAL ADMISSIONS 657 (29·86)

INFLUENZA CASES 8 ·86

MEAN OF TOTAL ADMISSIONS 29·86 PER WEEK

39 36 33 30 27 24 21 18 15 12 9 6 3

TOTAL RESPIRATORY CASES 184 (8·86)

PNEUMONIA. 26 (1·18)

WEEKLY MEAN OF RESPIRATORY CASES 8·86

15 12 9 6 3

TOTAL OF NERVOUS CASES 86 (3·91)

MEAN OF NERVOUS CASES 3·91

6 3

TOTAL OF DIGESTIVE CASES 53 (2·4)

MEAN OF DIGESTIVE CASES 2·4

6 3

PERCENTAGE OF CASES TO TOTAL ADMISSIONS

TOTAL RESPIRATORY MEAN, 28·0%

TOTAL DIGESTIVE MEAN, 8·06%

INFLUENZA MEAN, 1·23%

NERVOUS MEAN, 13%

MEAN % OF RESPIRATORY TO TOTAL 28·0%

NERVOUS MEAN 13%

DIGESTIVE, 8%

INFLUENZA 1·2%

54 51 48 45 42 39 36 33 30 27 24 21 18 15 12 9 6 3

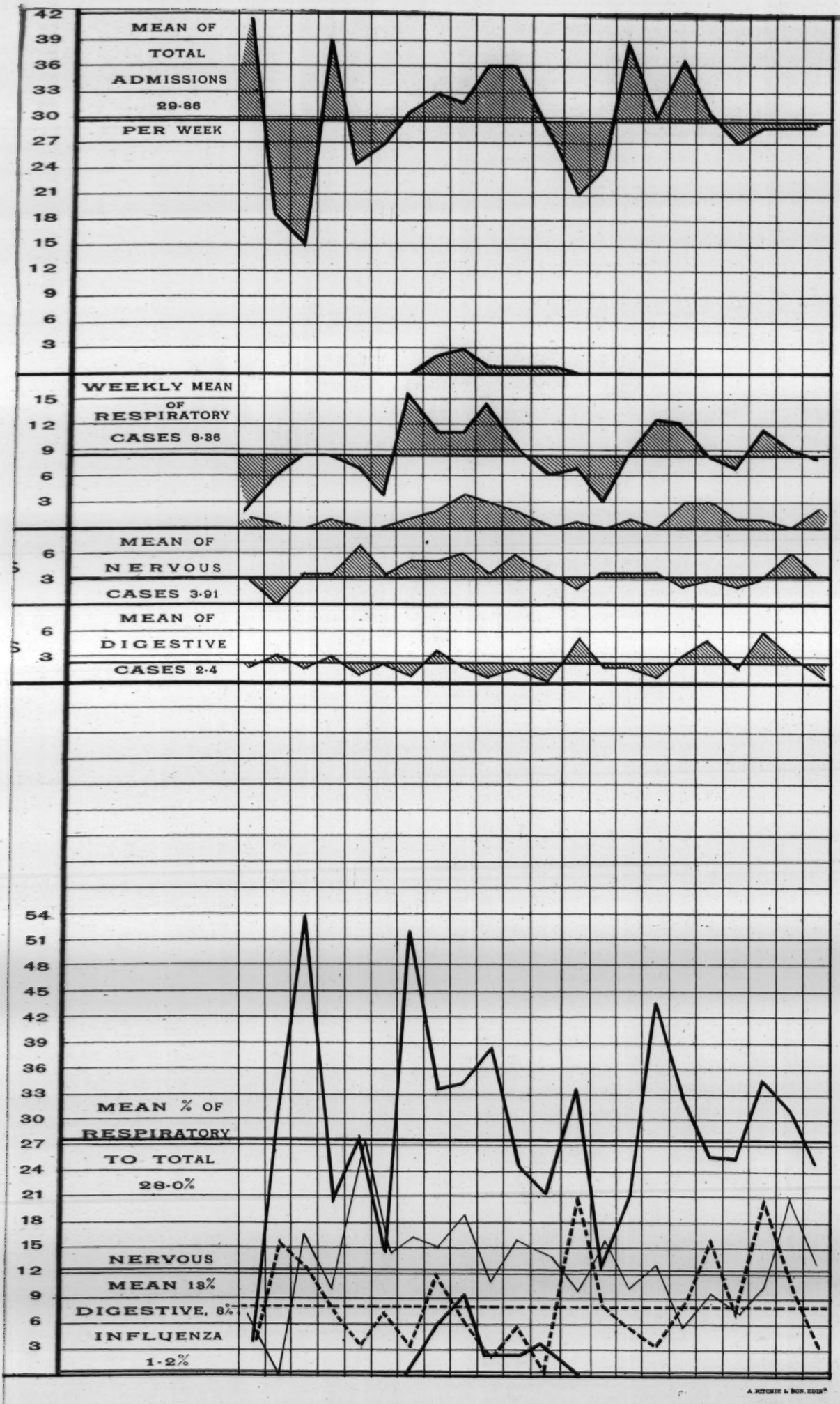
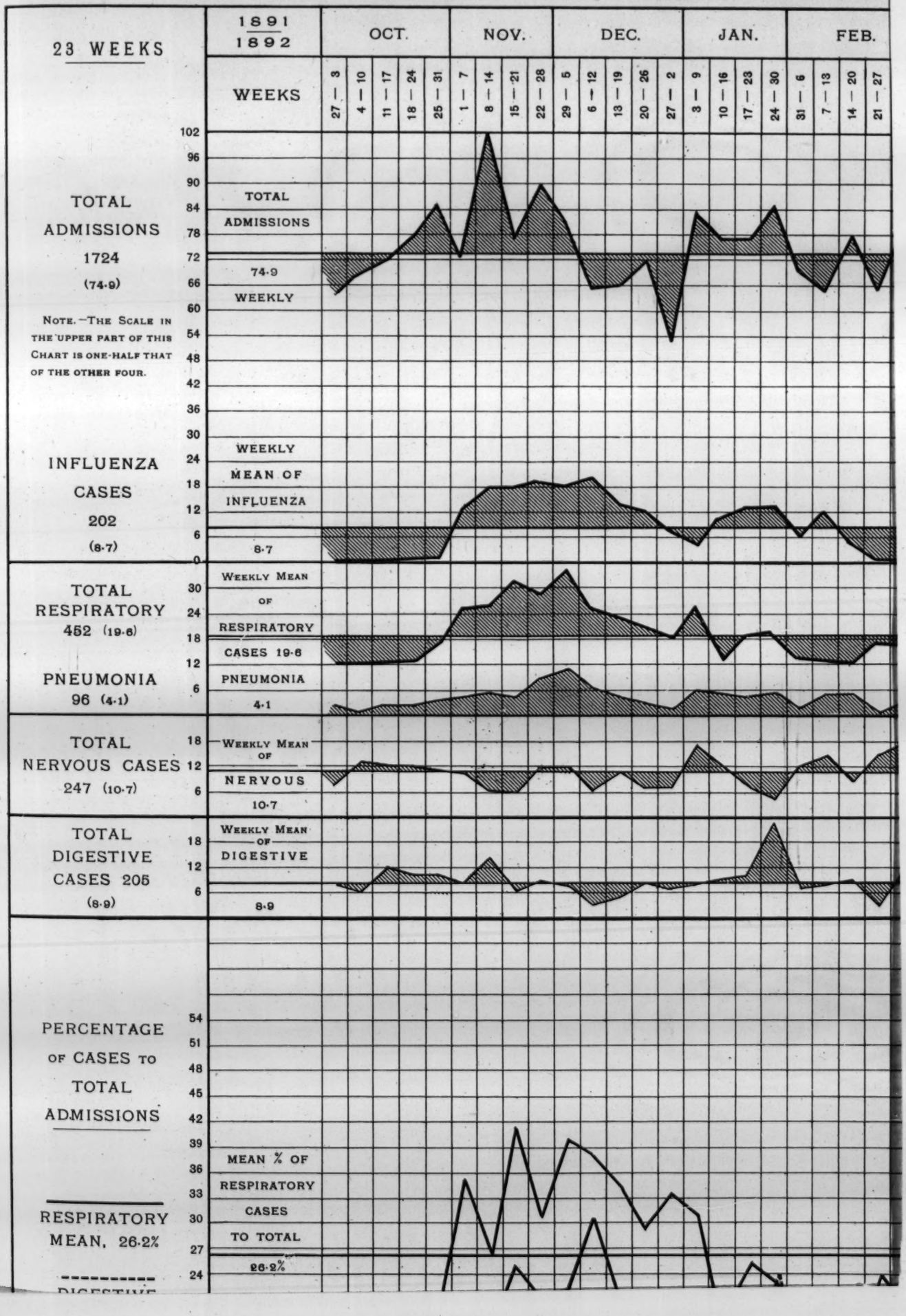
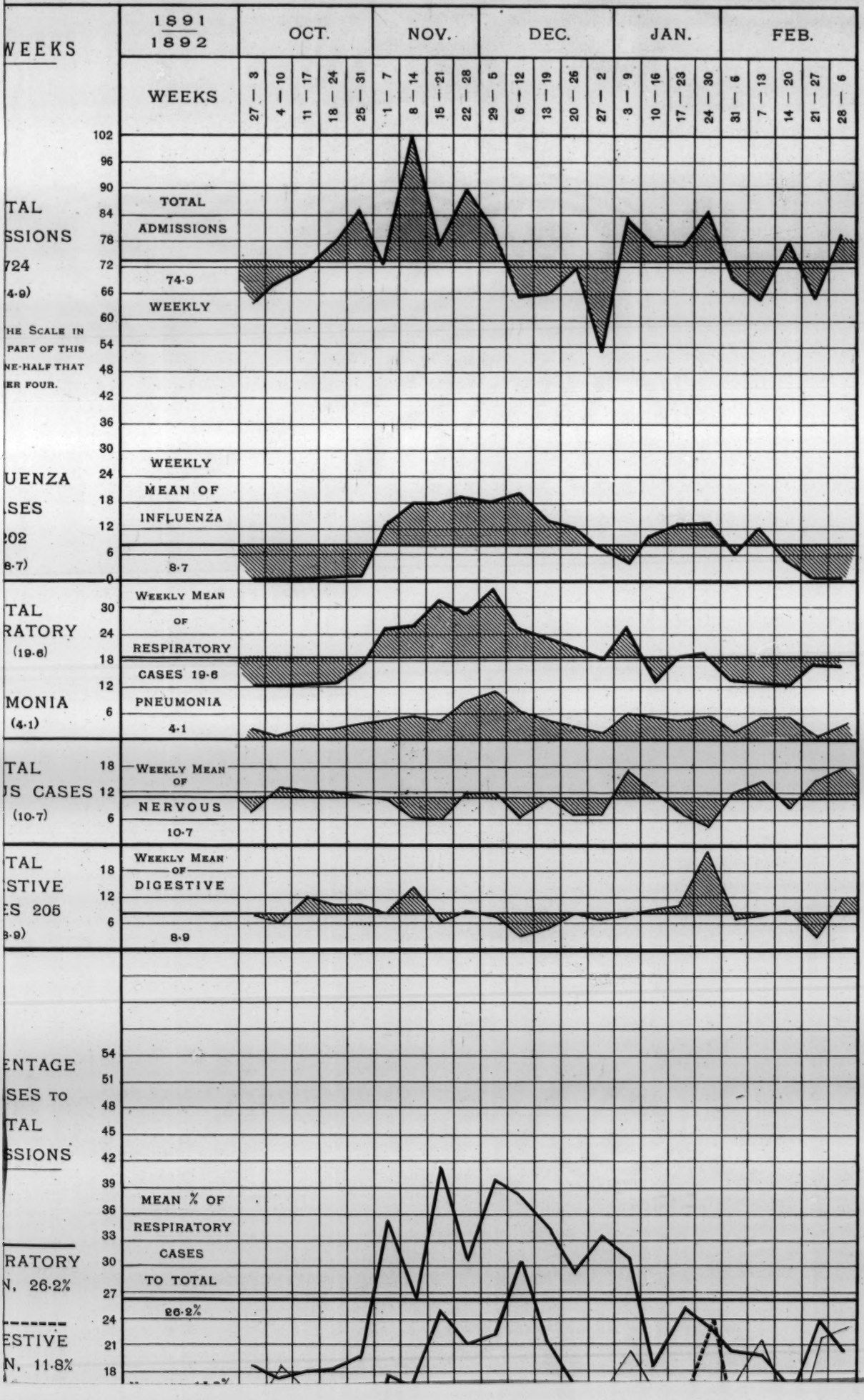
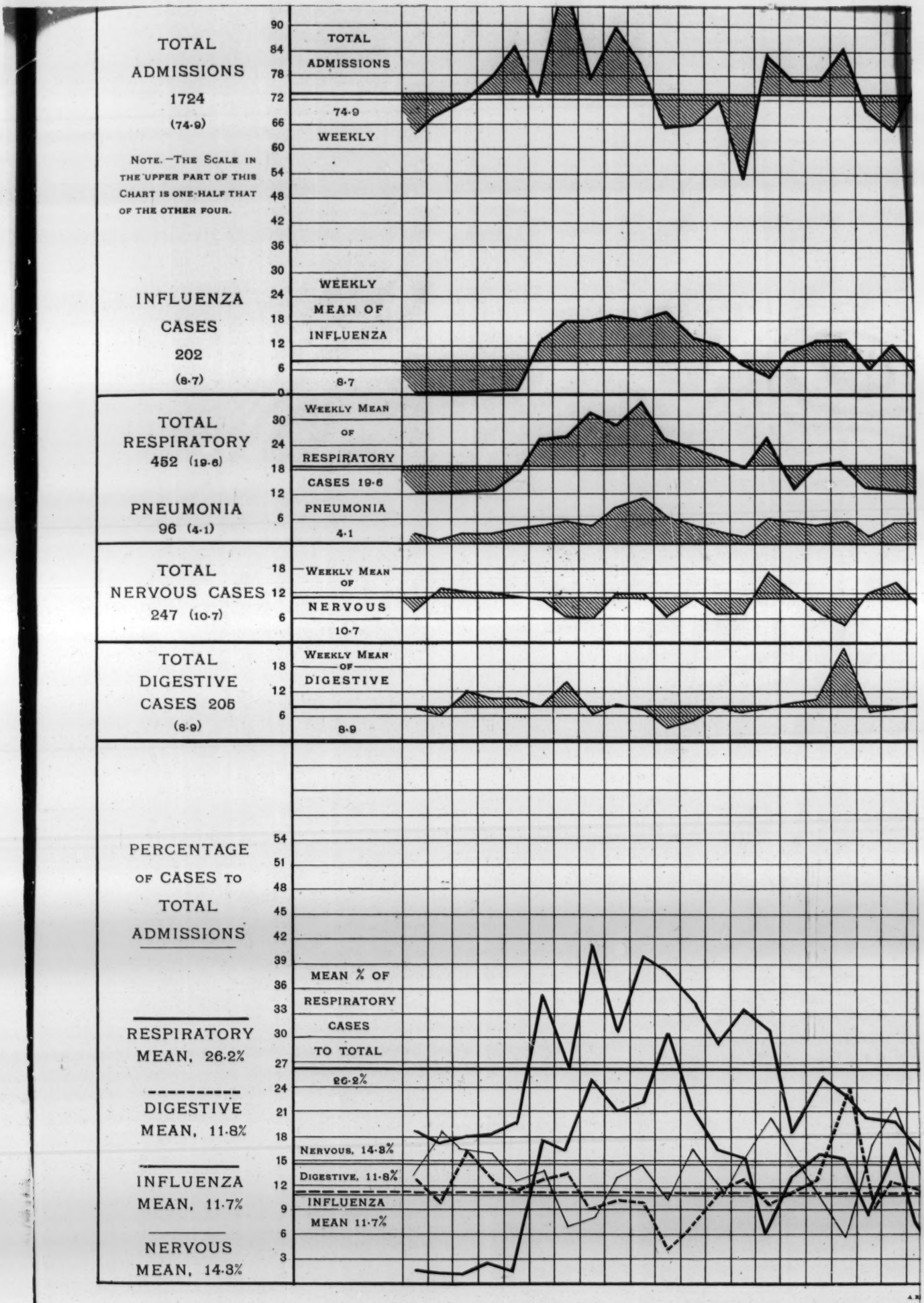

42
39
36
33
30
27
24
21
18
15
12
9
6
3
MEAN OF
TOTAL
ADMISSIONS
29·86
PER WEEK
15
12
9
6
3
WEEKLY MEAN
OF
RESPIRATORY
CASES 8·36
6
3
MEAN OF
NERVOUS
CASES 3·91
6
3
MEAN OF
DIGESTIVE
CASES 2·4
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
MEAN % OF
RESPIRATORY
TO TOTAL
28·0%
NERVOUS
MEAN 13%
DIGESTIVE, 8%
INFLUENZA
1·2%

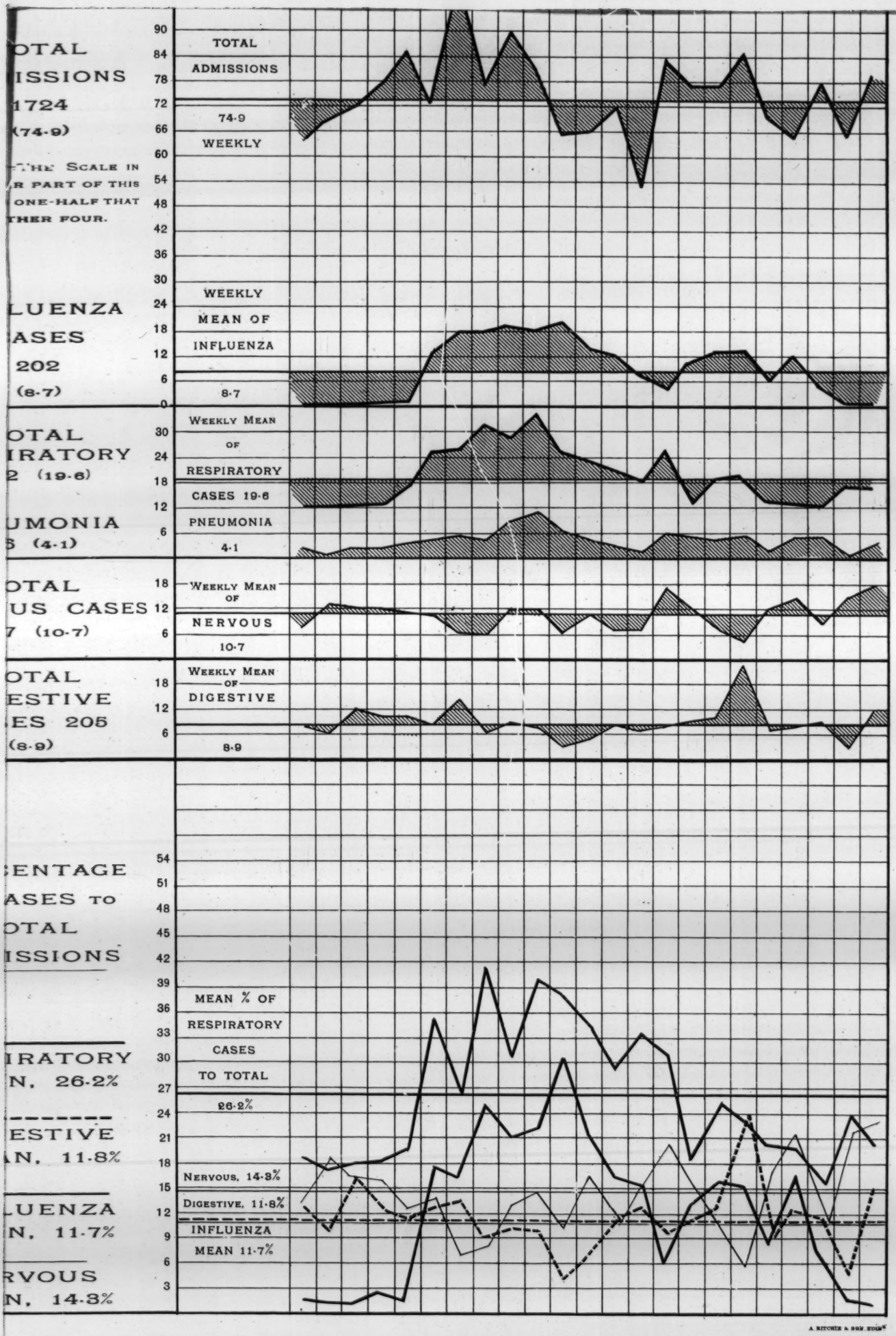
CHART VI.—EPIDEMIC OF INFLUENZA IN THE WINTER OF 1891-1892.



RT VI.—EPIDEMIC OF INFLUENZA IN THE WINTER OF 1891-1892.




TOTAL ADMISSIONS 1724 (74·9)
Note.—The Scale in the upper part of this Chart is one-half that of the other four.
INFLUENZA CASES 202 (8·7)
TOTAL RESPIRATORY 452 (19·6)
PNEUMONIA 96 (4·1)
TOTAL NERVOUS CASES 247 (10·7)
TOTAL DIGESTIVE CASES 205 (8·9)
PERCENTAGE OF CASES TO TOTAL ADMISSIONS
RESPIRATORY MEAN, 26·2%
DIGESTIVE MEAN, 11·8%
INFLUENZA MEAN, 11·7%
NERVOUS MEAN, 14·3%
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
TOTAL ADMISSIONS
74·9
WEEKLY
WEEKLY MEAN OF INFLUENZA
8·7
Weekly Mean of Respiratory Cases 19·6
Pneumonia
4·1
Weekly Mean of Nervous
10·7
Weekly Mean of Digestive
8·9
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
Mean % of Respiratory Cases to Total
26·2%
Nervous, 14·3%
Digestive, 11·8%
Influenza Mean 11·7%


OTAL
ISSIONS
1724
(74·9)
THE SCALE IN
R PART OF THIS
ONE-HALF THAT
THER FOUR.
LUENZA
ASES
202
(8·7)
OTAL
IRATORY
2 (19·6)
UMONIA
3 (4·1)
OTAL
US CASES
7 (10·7)
OTAL
ESTIVE
ES 205
(8·9)
ENTAGE
ASES TO
OTAL
ISSIONS
IRATORY
N, 26·2%
ESTIVE
N, 11·8%
LUENZA
N, 11·7%
RVOUS
N, 14·8%
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
TOTAL
ADMISSIONS
74·9
WEEKLY
WEEKLY
MEAN OF
INFLUENZA
8·7
30
24
18
12
6
WEEKLY MEAN
OF
RESPIRATORY
CASES 19·6
PNEUMONIA
4·1
18
12
6
WEEKLY MEAN
OF
NERVOUS
10·7
18
12
6
WEEKLY MEAN
OF
DIGESTIVE
8·9
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
MEAN % OF
RESPIRATORY
CASES
TO TOTAL
26·2%
NERVOUS, 14·8%
DIGESTIVE, 11·8%
INFLUENZA
MEAN 11·7%

XVII.—*The ς′ of Diophantus.* By Prof. D'Arcy Wentworth Thompson.

(Read 18th May 1896.)

The Arithmetical, or, as we should say, Algebraic, Problems of Diophantus involve a single unknown quantity, symbolised by ς′ or ς^{o}′. The number for which this symbol stands is described as πλῆθος μονάδων ἄλογον,* and is spoken of as ὁ ἀόριστος ἀριθμός, the undefined number, or simply as ὁ ἀριθμός, the number, *par excellence*, of the problem in question.

By all commentators, with but one exception so far as I know, the ς′ of Diophantus is taken as an abbreviation of ἀριθμός, and I find the same statement made unquestioningly in the standard *Palæography* of Gardthausen. The mathematicians, while expressing no doubt as to the fact, show, however, in some cases, a clear enough perception of the difficulty of accounting for such an abbreviation, and are not all agreed as to its more precise origin. Nesselmann, Cantor, and most others, treat the ς as the final letter of ἀριθμός: Heath, who devotes many pages to a discussion of the subject, puts forward, as an alternative and preferable hypothesis, a suggestion that the ς may be a corrupt cursive abbreviation of the two first letters αρ of the same word.†

Objections to these two theories, or modifications of a theory, are easy to find, and it is not necessary to discuss all the difficulties involved in the acceptance of either. The first, viz., that ς′ represents the last letter of ἀριθμός, is demolished over and over again, for not only is improbability written on the face of it, but it is incompatible with the occurrence of such inflected forms as ς^{ου}, ς'' (*cf.* τ'' = τόν), ςς^{οί}, ςς^{ων}, &c. The other, viz., that ς = αρ, leaves unexplained the alternative form ς^{o}′.

In my opinion, the ς′ has no connection with ἀριθμός, but is the initial letter of σωρός, a heap.

This view is countenanced by the following circumstances:—

1. We are now dealing with an *initial* letter, as in the contractions used by the same writer and by others for such words as δύναμις and κύβος.

* I am not quite content with Mr Heath's rendering (*Dioph. of Alex.*, p. 57) of πλῆθος μονάδων ἄλογον as "a number of units of which no account is given, or undefined," but I rather think that ἄλογος is here used in a more technical sense. The especial significance of ἄλογος is *irrational*, usually in the sense of "surd," *i.e.*, a number having no determinable "ratio": I take it here to refer, in a similar way, to a number whose "ratio" is not yet determined. The equivalent phrase ὁ ἀόριστος ἀριθμός is precisely comparable to the Aristotelian ἀόριστος δυάς. ἡ ἀόριστος δυάς is, in our nomenclature, $2n$ or $2x$; and the statement (Arist., *Met.*, xii. 7, 1081*a*) that ὁ ἀριθμός ἐστιν ἐκ τοῦ ἑνὸς καὶ τῆς δυάδος τῆς ἀορίστου, simply means that any number can be expressed either as $2n$ or $2n+1$. In like manner ὁ ἀόριστος ἀριθμός is n or x.

† The one writer who declines to commit himself as to the derivation of the ς from ἀριθμός is Gow (*Hist. of Gk. Mathem.*, p. 108, footnote); the symbol, he says, "may be Egyptian, or Indian, or Babylonian, and may reveal an entirely unknown chapter in the history of mathematics." He is inclined to look for the origin of the ς (and also of the Diophantine ϛ) in some pictorial hieroglyph.

2. The contractions appended to the symbol in the inflected cases correspond with the declension of the noun.
3. As we commonly find for δύναμις and κύβος not merely the initial letter, but rather δ^{υ}, κ^{υ}, so we find, instead of our ς′, at times $\varsigma^{o'}$. I do not know how far, in the age and domicile of DIOPHANTUS, we might or might not reasonably expect to find a confusion in manuscript between *o* and *ω*; but in this particular instance the relation between σωρός and σορός may atone for any palæographic difficulty.
4. The ordinary meaning of σωρός is in a fair degree akin to the sense required.
5. The same symbol ς′ occurs several times in MSS. of the *Arenarius* of ARCHIMEDES (*vide* HEIBERG, *Archimedis Opera Omnia*, vol. ii. p. 268), where it has hitherto been rendered by ἀριθμός, and it seems to me that there also we derive advantage by a substitution of the new reading.

If we be induced by these considerations to accept the rendering σωρός, we are next led on to a point of very great interest, and of much value in authenticating the hypothesis. For we learn that to the Egyptian mathematician AHMES, the symbol and name for the unknown quantity was *hau*, a heap, 2000 years before DIOPHANTUS; and we may place this coincidence alongside the information that is growing in our hands as to the connection of the arithmetic or algebra of DIOPHANTUS with Egyptian sources. Certain it is, as BONNYCASTLE * long ago remarked, "that DIOPHANTUS was not the inventor of algebra, as has been generally imagined . . . since he nowhere treats of the first principles and leading rules of the science, as a writer in the infancy of the art would have done; but proceeds, at once, to the resolution of a particular class of indeterminate problems . . . which even at present are generally considered as forming one of the most difficult branches of pure analysis."

Dr GOW and others have surmised that HERON was an Egyptian, just as a generation ago DE MORGAN suspected that DIOPHANTUS was not a Greek. "Such evidence as this," says Dr GOW,† after a compendious comparison of the methods of HERON and of AHMES, "goes a long way to confirm the suspicions not only that HERON was an Egyptian, but also that algebra was an Egyptian art, and that the symbolism of DIOPHANTUS was of Egyptian origin."

And, in regard to the Egyptian sources of his knowledge, not very long ago, in the *Wissensch. Beilage d. Leipziger Zeitung*, April 27, 1895, Dr HULTSCH said briefly, but explicitly, "Nur beiläufig konnte darauf hingewiesen werden, dass die Diophantischen Aufgaben nichts Anderes als eine, allerdings vervollkommnete Nachbildung ägyptischer Aufgaben der *verhältnissmässigen Theilung* sind. Charakteristisch für die ägyptische Logistik ist die vollständige Beherrschung und geschickteste Verwendung der Einheitsschlusses." And HULTSCH further remarks, in a letter communicated to me by Dr GOW,

* *Treatise on Algebra*, London, 8vo, 2 vols., 1820; vol. i. pt. i. p. 225. This writer's interesting and sympathetic account of the Diophantine analysis is not alluded to by HEATH.

† *Hist. of Math.*, p. 286.

"diese meine Vermuthung ist jetzt bestätigt worden durch *Michaelis Pselli epistola inedita*, in Diophanti Op. ii. pp. 37, 3–6, 38, 22–39, 6 [ed. TANNERY]."

Before I conclude, I am bound to admit that there seems to me to be one serious defect in my theory as I have stated it in the foregoing account, to wit, that "a heap," which already conveys the notion of a solid, is not what we should expect as the starting-point of a series where δύναμις and κύβος are to follow consecutively. To remedy this defect, I offer two suggestions, which are not alternatives, but may be both partially and complementarily true. The σωρός may convey the idea not necessarily of a heap, but merely of *a chain* of links or units, and the passage then becomes natural and legitimate to the square and cube, with their connotations of area and solid. Or again, if we dwell on what has been said above, and especially on the passage I have quoted from HULTSCH, the possibility presents itself to us that the σωρός may relate not so much to the "indefinite number," the unknown quantity, the x itself, as to the method to be employed for its discovery, the factors by whose substitution it was to be solved. The analogy of the *heap* or *chain* of syllogisms, the *acervus* or σωρείτης of the logicians, suggests to me that the word σωρός here may not be simply a metaphor drawn from a heap of sand, with its myriad grains taken in the gross, but may be a direct allusion to that resolved *chain* of factors which is the distinctive feature of the Diophantine analysis. I find not a little support to this view in ARISTOTLE'S use of the word in the *Metaphys.*, vii. 17, 1041*b*, τὸ ἔκ τινος σύνθετον οὕτως ὥστε ἓν εἶναι τὸ πᾶν, ἀλλὰ μὴ ὡς σωρὸς ἀλλ' ὡς ἡ συλλαβή, where it is as clear as possible that there is, in contrast to συλλαβή, a sense of disjunction in σωρός, antagonizing and predominating over the merely collective notion of a heap. If all this be so, it is as true of the *hau* or "heap-calculus" of the Egyptian as of the σωρός of him who wrote in Greek; it applies to the fractions of AHMES as to the factors of DIOPHANTUS. In regard both to method and to nomenclature, to the processes both of logical and of mathematical analysis, it may help us to link together the Alexandrine with the Theban, and to discern Antiquity learning of the Antiquity before. Though it is but a little matter in itself, it reminds us that a stream of thought flowed down out of Ancient Egypt into the Western World, from the River to the Sea; it points to a descent of traditional science and a continuity of intellectual activity, reaching down to the Silver Age of Imperial Rome from the Scholar-Priesthood of the Shepherd Kings. *Hæc Ægyptia quondam, nunc et sacra Romana sunt.*

XVIII.—*On Torsional Oscillations of Wires.* By Dr W. Peddie. With Two Plates.

(Read 16th March 1896.)

About two years ago I communicated to this Society a paper on the above subject, which was printed in the *Philosophical Magazine* (1894). The object of the investigations therein discussed was the determination of the law of decrease of torsional oscillations when the range of oscillation was large in comparison with the palpable limits of elasticity. An equation of the form

$$y^n(x+a)=b,$$

where y represents the range of oscillation, and x represents the number of oscillations which have taken place since the commencement of the observations in any one experiment, was found to give an exceedingly close representation of the results. The values of the quantities n, a, and b depend on the magnitude of the initial oscillation, and on the previous treatment of the wire. It was also found that, when the oscillations were allowed to die away to a sufficient extent, the value of n tended to diminish. The oscillations were practically isochronous.

It was shown further that the above formula could be deduced from the assumptions (1) that the loss of energy per oscillation is proportional to a power of the angle of oscillation, and (2), that, apart from this loss, Hooke's Law is obeyed. The latter assumption may be regarded as completely justified by the observations of G. Wiedemann, who showed that, after a rod has been "accommodated" by a few twists, in opposite directions alternately, to a given maximum, Hooke's Law was followed in all subsequent twists in one direction so long as the original maximum was not exceeded. The accuracy of the former assumption is therefore to be gauged by the completeness with which the formula suits the results of observation.

The conditions under which the resilience has maximum or zero values were discussed, and an expression, connecting the angle of "set" with the angle of torsion, was also deduced, and was tested by means of Wiedemann's observations, the agreement being very complete. And it was further pointed out that the well-known law of "compound interest," found by Lord Kelvin to hold in the case of very small oscillations, follows as a particular case when $n=0$.

The initial range had nearly a constant value in all the experiments discussed in the first paper, and therefore no attempt could be made in it to consider the variations of the parameters n, a, and b, consequent on changes in the initial conditions. In the present paper, three separate sets of experiments are described. Full confirmation is given of the accuracy of the above formula, and the nature of the variations of the parameters is investigated.

Modification of the Apparatus.

In the former experiments, an iron wire 89·1 cm. in length, and 0·1011 cm. in diameter, was used. Before measurement, the ends of the wire had been soldered into holes drilled axially in brass rods. One of these rods, with the wire suspended from it, was clamped in a vertical position. To the other rod, a lead ring, of considerable moment of inertia, was attached symmetrically. The oscillations were produced by twisting the wire in opposite directions alternately, by hand, the impulses being timed to suit the natural period of the wire, until the required maximum was reached. The unavoidable pendulum-swings of the wire were then damped out by hand as rapidly as possible.

The same wire was used in the new series of experiments, but the upper rod was passed through a cylindrical hole, of the same diameter as the rod, drilled vertically through a fixed metal block. The rod ended in a head which rested on the upper horizontal face of the metal block and thus supported the oscillating system. A horizontal lever, attached to the head, resting normally in contact with a stop, could be turned out from, and back to, the stop through a considerable angle. In this way, large or small oscillations could be readily produced. Two such double motions of the lever, properly timed, were found to be sufficient to produce the largest oscillation desired.

The angle of oscillation was read off on a scale, attached to the circumference of the lead ring, by means of a telescope placed a short distance away. Formerly, the reading was got by means of a fixed pointer placed close in front of the scale; in the new observations, it was got by means of a fibre placed in the focus of the telescope.

In the former experiments, the lead ring was of such moment of inertia that ten complete oscillations were performed in about 80 seconds. In the new series, for a reason which will appear subsequently, a lead ring of the same weight but of greater moment of inertia was used. When tested during the course of the first experiment (12.7.94), and subsequently at the date 25.7.94 after a number of experiments had been performed, nineteen complete oscillations took place in 300 seconds.

Symmetry of the Oscillations.

In the former experiments, positive elongations alone were read; for the period of oscillation was too short to admit of both elongations being read with accuracy. The zero from which the elongations were reckoned was the point about which the oscillations took place when the motion had died down to a large extent. This is a point about which the oscillations must be symmetrical, should such a point of symmetry exist throughout the whole motion. But the existence of such a point cannot, from the nature of the problem, be postulated *a priori*. The first positive elongation causes a considerable positive set of the zero from its original position.

The first negative elongation does not entirely destroy the positive set. The second positive elongation increases it, and the second negative elongation does not entirely remove this increase; and so on. Thus the conditions under which successive oscillations occur are continually varying, and one cannot therefore assume without proof that the oscillations are symmetrical about a fixed point. As a matter of fact, the present experiments have shown that there is a fixed point of symmetry.

If an arbitrary scale reading β be chosen as the zero in any one experiment, and if successive positive and negative elongations α, γ, be read from this zero, the point about which the oscillations are symmetrical must be $\beta+(\alpha-\gamma)/2$. A number of results, which show that this quantity is practically constant in any one experiment, are given in Table I. The dates of the experiments are given in the left-hand column. The number of complete oscillations which had taken place since the commencement of the experiment are given in the first row, and the corresponding values of the quantity $\beta+(\alpha-\gamma)/2$ appear in the various rows and columns underneath. The last column contains the values of the zero which were observed when the oscillations were stopped.

There may be an error of $\pm 0{\cdot}1$ in any of the calculated quantities. In the columns headed $\frac{1}{2}$ and 1, the error may be much greater, because the elongations decreased with great rapidity at first.

General Outline of Experiments.

Three series of experiments were carried out. The first of these, extending from the date 12.7.94 to the date 4.8.94, consisted of forty-two experiments. The treatment of the wire throughout this period was as nearly uniform as possible, and the initial range of oscillation was varied considerably in the different experiments. On those days on which small initial ranges only were used, the wire was oscillated with a large initial range after the observations were completed, so as to preserve the uniformity of treatment.

A second series, made between the dates 16.7.95 and 26.7.95, consisted of thirteen experiments. The main object was the investigation of the effect of fatigue. The wire was oscillated for some time, through as large a range as was possible with the given range through which the lever could be turned, before each experiment was begun—the number of complete oscillations varying from 1 to 200.

A third set, in which the initial ranges were on the whole smaller than those previously employed, consisting of ten experiments, was obtained between the dates 9.12.95 and 24.12.95.

Before the second set was begun, the wire was oscillated, with a large initial range, once or twice per day for about three weeks. Before the third set was begun, it was similarly oscillated, about once per day, for five or six weeks.

In those experiments in which the initial range had as great a value as could be attained conveniently, the range fell to about half its initial value in one oscillation.

First Method of Determining the Constants.

In the first determination of the values of the quantities n, a, and b in the expression $y^n(x+a)=b$, use was made of the equations—

$$m^n=\frac{x_3-x_2}{x_2-x_1},$$

$$a=\frac{x_2^2-x_1x_3}{x_1+x_3-2x_2},$$

where $y_1=my_2=m^2y_3$, a suitable value being assigned to m. Three sets of values of y_3, y_2, and y_1 were chosen. These were respectively 5, 10, 20; 4, 8, 16; and 4, 7, 12·25 in all the cases in which the values of the quantities n, a, and b were determined by this method with two exceptions. In the experiment of date 16.7.94, the sets chosen were 5, 10, 20; 6, 10, 16·7; and 5, 8, 12·8; in that of date 4.8.94 (2) the sets were 3·5, 7, 14, and 4, 7, 12·25. These constant sets were chosen in order that, as far as possible, the determination of the quantities n, a, and b might be made under like conditions in the different cases. The arithmetical means of the values obtained for n, a, and b were then taken. It was hoped that, in this way, it might be possible to make out a systematic variation in the value of n as the value of the initial range was varied. But no indication of any change could be found, though the initial range was varied from its greatest value to about one-quarter of its greatest value; and the variety of the results obtained showed that any change which really existed was entirely hidden by irregularities arising in the observations themselves.

The columns headed n, a, and b in Table II. contain the averages; those headed n_1, n_2, and n_3 contain respectively the values of n as calculated from the three sets of values of y in the order specified above; and the column headed θ_0 gives the values of the initial range. Although these results are not subsequently employed, they are tabulated because they verify the conclusion, made in the first paper, that there is a slow diminution in the value of n as the oscillations die away.

Second Method of Determining the Constants.

Since a method of evaluating the quantities n, a, and b, dependent on the selection of particular points on the experimental curves, seemed to be incapable of sufficient accuracy for the indication of systematic variations in the value of n, it became necessary to use a method which gives values suiting, on an average, all points of any curve. Such a method is at once evident if we write the equation in the form—

$$n \log. y + \log. (x+a) = \log. b.$$

If the proper value of a be chosen, and if values of log. $(x+a)$ be plotted vertically, while corresponding values of log. y are plotted horizontal, the points thus obtained lie on an average on a straight line, and the tangent of the angle which this line makes

with the horizontal axis is numerically equal to the value of n. The equation then gives the value of b if values of x and y, corresponding to a point on the line, are inserted in it. If too large a value of a has been assumed, the line will be curved from the origin; if too small a value has been assumed, the line will be curved towards the origin.

First Series of Experiments.

In the above way the constants were determined in all the cases included in the first series of experiments after the date 24.7.94. The results are given in Table III. It is evident that there is no stronger indication of systematic variation in the values of the quantities than was given by the former method of determination. On the whole, the value of n seems to be greater when the initial range is small. But no stress can be laid on this result, for, when the range is small, a possible error in an observed value of y is a large fraction of its total amount. Again, possible observational errors cause the graph to appear practically straight throughout a considerable extent, although different values of a are chosen in plotting it; and this causes an uncertainty in the deduction of the values of n and b which increases when the initial range is small. The values of n and b, given in the table, were those which were obtained from the *first assumed* probable value of a which made the graph sufficiently straight.

Second Series of Experiments.

It became evident that it was necessary to carry out another series of experiments, under distinctly different conditions, in order to re-test the question of systematic variation, or to determine if the results obtained in the two series had any aspect in common. The results of the second series are contained in Table IV. The numbers which are given in that table are not, in some cases, those which were at first adopted. But theory indicated, as will be found subsequently, that the product nb might be constant, and it was seen to be so nearly constant throughout such a large number of the cases, that, in those cases in which its value differed much from the average, a recalculation of the quantities was made—a being altered in such a way as to make nb take a value not much different from that observed on the average in the other cases. It was in general found that the change thus made brought the calculated values of y into closer agreement with the observed values.

Throughout this series, large initial ranges of oscillation were employed, and the various experiments practically differed only in the amount of fatigue to which the wire was subjected. The amount of fatigue is indicated in the column headed N, which gives the number of complete large oscillations which were given to the wire before the observations were commenced. The effect of fatigue in diminishing b and increasing n is very marked. That it is also persistent is evident on a comparison of the cases in which N had the value 1, and of the two cases in which N had the value 50.

Third Series of Experiments.

Since, in the preceding series, large values of the initial range had alone been used, the third series was undertaken with the object of testing the constancy of the product nb when the initial angle was small. The results are contained in Table V. The wire was not fatigued by oscillation before each experiment. In the first two experiments, the value of θ_0 was large, and a comparison of the values of n, in these cases, with the values of n in similar cases in the first and second series of experiments, shows that the effect of the great fatigue induced in the second series has persisted throughout the period of four and a-half months which elapsed between the completion of the second series and the commencement of the third.

Constancy of the Product nb.

When the product nb is made as small as 180, the convexity, towards the origin, of the curves in which log. $(x+a)$ is plotted against log. y is usually distinct; when the product is as large as 250, the concavity, towards the origin, of these curves is also in general distinct. Thus the evidence that the product had, throughout the second and third series of experiments, a constant value not much different from 200 is of considerable strength. It is confirmed also by the results of the first series as given in Table III. Although these data were not determined with special precautions to obtain the best result, the products, with very few exceptions, fall within the limits just specified. In the particular exception 3.8.94 (1), the scale readings differed greatly, and for no obvious reason, from the readings got in the experiment 3.8.94 (3) under nearly identical conditions. And, in the exception 4.8.94 (1), the scale readings differed greatly from those which were obtained in the experiment 3.8.94 (4) under the same conditions. These two exceptions stand alone, in this respect, in all the series of observations. A new determination of the quantities n, a, and b was made, so as to give products of n and b not greatly differing from 200.

The results are given in Table VI. In almost every case these values of the quantities were found to give better agreement with the results of observation than the values given in Table III. This was, for example, the case in the experiment 4.8.94 (2).

Variation of n and b.

A comparison of the values of n and b in Tables IV., V., and VI. shows that the effect of increased initial range is of the same kind as the effect of fatigue. Fatigue causes a distinct and persistent increase in the value of n, and increase of the initial range also causes an increase in the value of n. Probably, if the wire were fatigued day after day by oscillation to a large and definite extent for a considerable period, a definite relation between n and θ_0 would become apparent. In the present series of experiments, no such relation can be established, for it is impossible to separate the effects of increased initial range and of fatigue. This is well brought out in fig. 2. The

single points show the values of n and θ_0 in the first series of experiments, Roman numerals being used to indicate the points corresponding to the first twelve experiments of the series. Points surrounded by circles indicate the values of n and θ_0 in the second series, the values of N given in Table IV. being placed alongside. The crosses give the results of the third series of experiments.

Explanation of Diagrams.

Fig. 2 has just been discussed. Fig. 1 shows the curves obtained from the readings in the experiment 20.7.94 (2). The abscissæ give the number of complete oscillations which have taken place since the commencement of the experiment. The ordinates of the upper curve represent the excess of the positive elongations over 20. The ordinates of the lower curve represent the defect of the negative elongations from 20. The ordinates of the middle curve are the means of simultaneous ordinates of the upper and lower curves. This curve, therefore (p. 612), shows the elongations referred to the zero about which they are symmetrical. Points on that curve which correspond to the abscissæ 1, 2, 3, 5, 7, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, are taken. The straight line in the figure is drawn on the average through points, whose ordinates are obtained by taking the logarithms of each of the above-noted abscissæ increased by 9, and whose abscissæ are the logarithms of the corresponding ordinates of the middle curve. From that line the values of n and b were deduced in the manner stated on p. 614. Only the lowest point, whose abscissa is 1·42, lies to any extent off the line. The second lowest point corresponds to the ordinate 20·5 in the middle curve. If the ordinate were 19·9 the point would be on the straight line, so that the discrepancy is only 1·5 per cent.

Fig. 3 illustrates the determination of limits (p. 616) between which the value of the product nb must lie. The points in that figure have been plotted, in the way just described, from the results obtained in the fourth experiment made on the date 3.8.94. In one case the value 12 was given to a, and nb had the value 195. Within experimental errors, all the points lie on the straight line. In the upper system of points, a and nb have the values 14 and 167 respectively, and the convexity of the system towards the origin is apparent. In the lower system, a and nb have the values 10 and 221 respectively, and it is evident that there is a tendency towards concavity to the origin.

The points in fig. 4 constitute a similar set for the experiment of date 18.12.95. When $a=10$, $nb=182$, the system of points is convex towards the origin. When $a=9$, $nb=205$, the system is practically straight; and the rectilinearity is even more complete in the lowest set of points, with the values $a=8$, $nb=217$.

The numbers in Table VII. give the observational data from which the upper and lower curves in fig. 1 were plotted. The first, third, fifth, &c., numbers give the scale readings for the positive elongations, the second, fourth, sixth, &c., numbers give the scale readings for the negative elongations. The number of scale divisions contained in a complete revolution of four right angles was 46·1. Hence, to get the plotted

numbers, 46·1 has to be added to the first five positive elongations, and then 20 has to be subtracted from all positive readings; and the first negative reading must be called −1·5, all the negative readings being then subtracted from 20.

The waves which are observed on the experimental curves in fig. 1 are due to slight pendulum-wise oscillations of the wire, which could not be avoided when the torsional oscillations were large. They do not appear in the middle curve.

Test of the Accuracy of the Formula.

In Table VIII. a comparison of the results of observation with the results obtained by calculation is given for all the experiments in the three series. The upper row contains values of x, and succeeding pairs of rows contain the logarithms of observed and calculated values of y corresponding to the given values of x—the calculations being made from the formula

$$y^n(x+a)=b,$$

and the values of a, n, and b being those given in Tables IV., V., and VI. In the first series of experiments the observed value of y usually exceeds the calculated value at the end of the first oscillation ($x=1$) by more than a possible error of observation, and sometimes, at the end of the second oscillation, the difference considerably exceeds one per cent. of the value of y. But it must be recollected that the above formula, from the point of view of theory (see former paper), can only be regarded as strictly applicable when two or three oscillations have taken place. With these exceptions, the results of observation and calculation may be regarded as being within the limits of possible observational error. When x is large, y is small, and the difference between observed and calculated values of y sometimes exceeds one per cent. of the value of y, but then so also does the possible observational error.

Critical Angle of Oscillation.

We have found that, in the present series of observations, the product of the quantities n and b may be regarded as being constant. Yet it is easy to see that this is a mere accidental circumstance depending on the particular unit in terms of which the angle of oscillation was measured. In terms of the unit here used we may write the equation in the form

$$ny^n(x+a)=\mathrm{B},$$

where B is an absolute constant. Suppose now that we choose the unit k times smaller. Then the new y (y' say) is k times the old, and we get

$$nk^ny^n(x+a)=\mathrm{B}'=\mathrm{B}k^n,$$

so that the most general form in which the equation can be put is

$$y'^n(x+a)=bk^n \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

instead of

$$y^n(x+a)=b \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now we have

$$-dy=\frac{1}{nb}y^{n+1}dx.$$

Hence, if, dividing y' by k, we reduce the equation, supposed to have been determined in the form (1), to the form (2), we see that the quantity k gives the value, in terms of the units used in (1), of an angle at which the rate of diminution of the oscillations is totally independent of the value of n. So also, since the loss of energy per oscillation is proportional to ydy (see former paper), this angle, which we may call the *Critical Angle*, is such that the loss of energy per oscillation is independent of n. At larger angles there is a greater loss when n is large than when it is small; at smaller angles there is less loss when n is large than when it is small.

Now n is increased by increase in the magnitude of the initial oscillation and also by fatigue. Hence we see that, at smaller angles than the critical angle, fatigue causes a decrease in the loss of energy per oscillation, and, at larger angles, fatigue causes an increase in the loss. Fatigue has no effect on the rate of loss of energy per oscillation at the critical angle.

Possible Explanation of the Existence of a Critical Angle.

Greater stability of a given group of molecules in a molecular system may consist in increase of (1) attractive forces amongst its components at a given distortion of the whole system, or (2) range of distortion of the whole system before rupture of the given group occurs. Either of these results may ensue upon a rearrangement of the constituents of the given group.

Decrease of (1) or (2) may occur provided that it is more than balanced by increase of (2) or (1) respectively. Thus there are five possible cases.

If increase of (1) alone occurred, there would, in all cases, be greater loss of energy in an oscillation of given magnitude.

If increase of (2) alone occurred, there would be less loss of energy in an oscillation of given magnitude.

If increase of (1) overbalances decrease of (2), greater loss occurs in all cases; if increase of (2) overbalances decrease of (1), less loss occurs in all cases.

Under none of these conditions can a critical angle occur.

When increase of (1) and (2) occur together, a critical angle exists when the effects balance as to loss of energy. At smaller angles increase of (2) must preponderate; at larger angles increase of (1) must preponderate.

A critical angle would also exist if, below it, increase of (2) overbalanced decrease of (1), while, above it, increase of (1) overbalanced decrease of (2). This necessitates that, at the critical angle, neither (1) nor (2) are changed. This could only mean that, at that angle, all configurations were equally stable. But, apart from that, it seems

certain that increase of (1) must, at all angles, be, on the whole, the determining cause of the change of configuration of the groups. Thus increase of stability, because of increase of (1) and (2) together, is the only case requiring consideration.

Numerical Value of the Critical Angle.

If we regard the scale-unit, used above in the measurement of y, as the true unit which gives nb constant, the dimensional data already given show that, in the wire used, the critical angle corresponds to a twist of about 0·09 degree per centimetre of length. But, in testing the constancy of nb, I frequently observed that the chosen value of nb was near the lower limit of the range of values, outside of which it could not be without causing distinct curvature in the system of points whose co-ordinates were log. $(x+a)$ and log. y. Yet, in other cases, the value of nb seemed to be near the upper limit. Thus, when $n=1$, 210 suits very well as the value of the product. And, if we put $Bk^n=210$ when $n=1$ and choose $k=0{\cdot}9$, we get $B=233$. If now $n=1{\cdot}22$, the product becomes 205; and these values very well suit, for example, the cases, 22.7.95, 25.7.95 with $a=6$, and 30.7.94 with $a=9$. Again, when $n=0{\cdot}7$ we get 230 as the value of the product, and this suits the case 24.12.95 with $a=210$. Also, if $n=1{\cdot}33$, the product becomes 202, which agrees well with 23.7.95 and 26.7.95 (2).

If we assume these values for k and B, the value of the critical angle is slightly less than that corresponding to a twist of 0°·1 per centimetre of length.

TABLE I.—*Showing the Constancy of the Zero of Oscillation.*

Date.	½	1	2	3	5	7	10	15	20	25	30	35	40	45	50	55	60	65	70	
12.7.94	29·8	30·1	30	30·05	30·1	30	30·1	30·05	30·1	30·15	30·15	30·2	30·05	30·15	30·1	30·15	30·2	30·2	30·2	30·14
13.7.94	30·15	30·15	30·15	30·15	30·1	30·2	30·2	30·15	30·15	30·15	30·15	30·2	30·15	30·1	30·15	30·1	30·1	...	...	30·16
16.7.94	29·9	30·05	30·15	30·1	30·1	30·1	30·1	30·05	30·1	30·1	30·1	30·15	30·05	30·15	...	...	...	...	...	30·12
17.7.94 (1)	30·1	29·95	30·25	30·25	30·15	30·15	30·2	30·25	30·2	30·2	30·25	30·2	30·25	30·2	30·3	30·25	...	...	...	30·23
17.7.94 (2)	31·8	30·95	31·15	31·2	31·1	31·25	31·35	31·2	31·35	31·3	31·25	31·3	31·25	31·25	31·3	31·3	...	...	...	31·3
18.7.94	31·85	31·45	31·3	31·6	31·45	31·45	31·5	31·6	31·6	31·45	31·55	31·55	31·7	31·6	31·5	...	...	...	...	31·56
19.7.94	31·1	31·15	31·25	31·4	31·25	31·25	31·35	31·4	31·5	31·35	31·3	31·45	31·45	31·45	...	...	...	...	...	31·4
20.7.94 (1)	42·1	31·45	31·45	31·45	31·45	31·55	31·45	31·4	31·45	31·5	31·5	31·55	31·5	31·45	31·35	...	...	...	...	31·47
20.7.94 (2)	31·75	30·85	31·0	31·05	31·05	31	31·05	31·15	31·2	31·05	31·1	31·15	31·2	31·2	31·15	31·15	31·15	...	...	31·16
21.7.94 (1)	31·6	32·25	31·65	31·55	31·6	31·7	31·45	31·7	31·7	31·75	31·65	31·8	31·8	...	...	...	...	...	...	31·71
21.7.94 (2)	31·75	31·8	31·6	31·6	31·65	31·7	31·7	31·7	31·8	31·7	31·75	31·85	31·8	31·75	31·8	...	...	...	...	31·76
23.7.94 (1)	31·5	31·7	32·0	32·1	32·2	32·2	32·15	32·2	32·2	32·15	32·2	32·25	32·2	32·2	32·18	32·15	...	...	...	32·2
23.7.94 (2)	31·8	32·0	32·05	32·05	32·05	32·1	32·05	32·05	32·05	32·05	32·05	32·1	32·05	32·15	32·05	...	...	...	...	32·09
24.7.94 (1)	32·55	32·5	32·5	32·8	32·9	32·95	32·15	32·85	32·85	32·9	32·9	32·9	32·85	32·95	32·9	32·85	...	...	...	32·9
26.7.95 (2)	38	36·5	36·5	36·55	36·55	36·6	36·66	36·6	36·65	36·55	36·6	36·6	36·6	36·65	36·6	36·65	...	...	...	36·6

TABLE II.—*Giving Values of n, a, and b, determined by the First Method.*

Date.	n_1	n_2	n_3	n	a	b	θ_0
12.7.94	1·010	0·869	0·839	0·903	15·40	249	31·2
13.7.94	1·060	1·034	1·028	1·041	12·62	308	24·5
16.7.94	1·012	0·843	0·843	0·915	15·60	257	33·0
17.7.94 (1)	1·100	1·022	1·022	1·041	9·67	264	45·0
17.7.94 (2)	0·965	0·902	0·887	0 918	11·47	206	56·5
18.7.94	...	...	...	1·043	8·00	224	55·5
19.7.94	1·020	0·972	0·986	0·991	8·23	203	54·0
20.7.94 (1)	1·022	1·085	1·032	1·046	8·30	225	43·0
20.7.94 (2)	1·000	1·057	1·027	1·028	7·99	208	52·0
21.7.94 (1)	1·087	1·043	1·020	1·050	8·40	224	44·5
21.7.94 (2)	...	...	...	0·982	9·10	200	51·0
23.7.94 (1)	1·093	1·054	0·979	1·042	8·50	222	44·5
23.7.94 (2)	1·057	1·016	0·992	1·022	9·92	218	24·0
24.7.94 (1)	1·090	0·941	0·913	0·981	9·56	196	38·2
24.7.94 (2)	1·099	1·023	1·015	1·046	8·10	209	33·5
24.7.94 (3)	1·031	1·030	0·945	1·002	8·10	190	33·5
4.8.94 (2)	...	1·017	1·014	1·016	16·00	242	14·4

TABLE III.—*First Determination of n and b by the Graphical Method.*

Date.	a	n	b	θ_0
25.7.94 (1)	8	1·035	203	46·0
25.7.94 (2)	8	1·000	185	49·4
25.7.94 (3)	8	1·021	193	39·8
27.7.94 (1)	8	1·030	204	42·5
27.7.94 (2)	8	1·038	194	40·9
27.7.94 (3)	8	1·035	198	38·7
30.7.94 (1)	8	1·059	213	36·3
30.7.94 (2)	9	1·030	212	29·7
30.7.94 (3)	9	1·040	214	25·7
31.7.94 (1)	10	1·045	216	20·3
31.7.94 (2)	10	1·029	215	24·0
31.7.94 (3)	10	1·004	210	24·9
1.8.94 (1)	10	1·000	207	28·1
1.8.94 (2)	12	1·012	217	18·5
2.8.94 (1)	10	1·020	217	28·3
2.8.94 (2)	12	1·025	219	17·2
2.8.94 (3)	14	1·044	220	13·9
3.8.94 (1)	16	1·267	336	10·8
3.8.94 (2)	8	1·018	194	42·5
3.8.94 (3)	20	1·007	189	10·0
3.8.94 (4)	12	1·000	195	16·5
4.8.94 (1)	14	1·043	255	16·3
4.8.94 (2)	14	1·064	247	14·4
4.8.94 (3)	40	1·024	339	6·4
4.8.94 (4)	40	1·061	275	6·2
4.8.94 (5)	10	1·058	222	19·9

TABLE IV.—*Results of the Second Series of Experiments.*

Date.	a	n	b	nb	θ_0	N
16.7.95	6	1·079	179	192	37·1	1
17.7.95	4	1·133	168	190	51·3	10
18.7.95	4	1·180	175	206	44·4	20
19.7.95	5	1·137	172	196	41·2	30
20.7.95 (1)	5	1·135	173	196	36·6	1
20.7.95 (2)	3	1·227	167	205	48·7	50
20.7.95 (3)	4	1·190	161	192	39·7	1
22.7.95	3	1·233	162	199	40·0	80
23.7.95	2	1·290	157	203	42·0	120
25.7.95	2	1·310	154	202	30·2	160
26.7.95 (1)	4	1·197	161	193	38·7	1
26.7.95 (2)	2	1·322	158	200	43·9	200
27.7.95	2	1·327	147	195	41·5	50

TABLE V.—*Results of the Third Series of Experiments.*

Date.	a	n	b	nb	θ_0
9.12.95	3	1·220	153	187	37·2
12.12.95	3	1·255	162	203	36·8
17.12.95	9	1·110	171	190	14·2
18.12.95	9	1·120	183	205	14·3
19.12.95 (1)	22	1·000	209	209	9·6
19.12.95 (2)	35	0·935	217	203	7·0
20.12.95 (1)	80	0·750	277	205	5·3
20.12.95 (2)	120	0·715	264	189	3·0
24.12.95 (1)	219	0·660	302	199	1·6
24.12.95 (2)	47	0·785	256	201	8·5

TABLE VI.—*Final Determination of n and b in the First Series.*

Date.	a	n	b	nb	θ_0
12.7.94	20	0·819	238	195	31·1
13.7.94	22	0·811	244	198	34·5
16.7.94	19	0·829	238	197	32·8
17.7.94 (1)	14	0·893	224	200	44·9
17.7.94 (2)	11	0·947	215	204	56·0
18.7.94	9	0·962	202	194	55·6
19.7.94	9	0·976	199	194	53·9
20.7.94 (1)	10	0·963	204	196	43·1
20.7.94 (2)	9	0·976	198	193	52·3
21.7.94 (1)	9	0·991	203	201	44·0
21.7.94 (2)	9	0·978	196	192	51·1
23.7.94 (1)	10	0·976	207	202	44·2
23.7.94 (2)	11	0·981	204	200	23·8
24.7.94 (1)	9	0·989	197	195	38·2
24.7.94 (2)	9	1·000	199	199	32·5
24.7.94 (3)	9	1·000	199	199	33·9
25.7.94 (1)	6	1·014	198	201	46·0
25.7.94 (2)	6	1·024	187	192	49·4
25.7.94 (3)	8	1·021	193	197	39·8
27.7.94 (1)	8	1·030	204	210	42·5
27.7.94 (2)	8	1·038	194	202	40·9
27.7.94 (3)	8	1·035	198	205	38·7
30.7.94 (1)	9	0·995	210	199	36·3
30.7.94 (2)	10	0·988	205	198	29·7
30.7.94 (3)	11	0·973	203	197	25·7
31.7.94 (1)	12	0·973	202	197	20·3
31.7.94 (2)	11	0·967	197	190	24·0
31.7.94 (3)	10	0·989	201	199	24·9
1.8.94 (1)	10	0·990	203	201	28·1
1.8.94 (2)	13	0·953	200	191	18·5
2.8.94 (1)	11	0·969	204	198	28·3
2.8.94 (2)	14	0·946	201	190	17·2
2.8.94 (3)	16	0·960	199	191	13·9
[3.8.94 (1)	30	0·875	234	194	10·8]
3.8.94 (2)	8	1·018	192	195	42·5
3.8.94 (3)	20	1·007	189	190	10·0
3.8.94 (4)	12	1·000	195	195	16·5
[4.8.94 (1)	18	0·910	219	200	16·3]
4.8.94 (2)	20	0·903	220	199	14·4
4.8.94 (3)	55	0·810	242	196	6·4
4.8.94 (4)	60	0·820	247	202	6·2
4.8.94 (5)	12	0·972	199	193	19·9

TABLE VII.—*Data for the Second Experiment of Date* 20.7.94.

37·40	41·09	37·24	35·60	34·65
44·60	21·54	24·97	26·63	27·53
11·16	40·64	37·07	35·48	34·66
8·48	21·97	25·19	26·73	27·63
5·37	40·21	36·97	35·47	34·67
12·22	22·32	25·43	26·88	27·76
2·68	39·77	36·83	35·42	34·62
14·32	22·64	25·65	27·04	27·75
0·98	39·36	36·68	35·33	34·53
15·75	22·95	25·74	27·04	27·74
45·78	38·99	36·50	35·22	34·42
16·83	23·27	25·82	27·06	27·80
44·76	38·72	36·29	35·06	34·38
17·75	23·60	25·94	27·14	27·87
43·92	38·50	36·14	35·03	34·39
18·53	23·93	26·07	27·24	27·97
43·29	38·27	36·07	35·02	34·37
19·23	24·25	26·26	27·36	28·04
42·66	38·04	36·03	34·96	34·32
19·88	24·46	26·44	27·45	28·01
42·04	37·78	35·92	34·90	34·22
20·48	24·63	26·51	27·45	28·03
41·54	37·52	35·76	34·77	34·14
21·05	24·79	26·56	24·47	...

TABLE VIII.—*Test of the Accuracy of the General Formula.*

Date.	Log. y	1	2		3	5	7	10	15	20	25	30	35	40	45	50	55
12.7.94	Obs.	1·380	1·314		1·265	1·199	1·149	1·093	1·013	0·940	0·870	0·813	0·770	0·724	0·690	0·643	0·602
	Calc.	1·288	1·265		1·240	1·191	1·154	1·100	1·018	0·945	0·879	0·822	0·771	0·730	0·685	0·644	0·608
13.7.94	Obs.	1·324	1·279		1·243	1·187	1·143	1·086	1·013	0·934	0·875	0·826	0·778	0·732	0·770	0·663	0·633
	Calc.	1·263	1·241		1·220	1·188	1·140	1·088	1·012	0·942	0·886	0·826	0·779	0·730	0·700	0·675	0·624
16.7.94	Obs.	1·394	1·318		1·267	1·204	1·149	1 093	1·013	0·944	0·875	0·819	0·770	0·716	0·690	...	...
	Calc.	1·300	1·268		1·245	1·198	1·152	1·099	1·013	1·944	0·877	0·822	0·773	0·724	0·690	...	...
17.7.94 (1)	Obs.	1·444	1·332		1·272	1·199	1·143	1·079	0·991	0·908	0·845	0·792	0·740	0·700	0·653	0·613	0·580
	Calc.	1·313	1·294		1·252	1·197	1·143	1·085	0·996	0·919	0·853	0·790	0·737	0·690	0·657	0·612	0·583
17.7.94 (2)	Obs.	1·446	1·330		1·265	1·190	1·130	1·064	0·973	0·886	0·813	0·756	0·708	0·653	0·613	9·580	0·556
	Calc.	1·350	1·292		1·259	1·198	1·140	1·069	0·970	0·888	0·821	0·762	0·708	0·661	0·614	0·576	0·546
18.7.94	Obs.	1·428	1·324		1·260	1·210	1·120	1·049	0·954	0·869	0·799	0·740	0·672	0·633	0·602	0·568	...
	Calc.	1·357	1·314		1·270	1·203	1·148	1·062	0·954	0·871	0·802	0·740	0·687	0·633	0·588	0·549	...
19.7.94	Obs.	1·425	1·316		1·250	1·170	1·114	1·049	0·939	0·857	0·785	0·716	0·672	0·623	0·580	...	...
	Calc.	1·330	1·288		1·246	1·180	1·120	1·043	0·939	0·857	0·787	0·724	0·668	0·623	0·580	...	...
20.7.94 (1)	Obs.	1·403	1·305		1·243	1·167	1·114	1·045	0·944	0·863	0·792	0·732	0·672	0·633	0·602	0·568	...
	Calc.	1·314	1·276		1·240	1·175	1·111	1·045	0·944	0·861	0·787	0·732	0·667	0·630	0·590	0·571	...
20.7.94 (2)	Obs.	1·420	1·312		1·248	1·170	1·111	1·037	0·929	0·850	0·778	0·716	0·672	0·623	0·580	0·544	0·505
	Calc.	1·328	1·285		1·243	1·177	1·116	1·037	0·933	0·849	0·784	0·721	0·665	0·616	0·574	0·538	0·509
21.7.94 (1)	Obs.	1·412	1·305		1·243	1·164	1·110	1·041	0·934	0·857	0·785	0·724	0·672	0·623	0·590	...	...
	Calc.	1·316	1·278		1·238	1·171	1·110	1·037	0·934	0·855	0·787	0·725	0·667	0·619	0·581	...	...
21.7.94 (2)	Obs.	1·410	1·308		1·246	1·164	1·104	1·037	0·934	0·850	0·785	0·716	0·663	0·613	0·568	0·532	...
	Calc.	1·326	1·285		1·249	1·180	1·105	1·010	0·932	0·852	0·777	0·717	0·655	0 609	0·568	0·530	...
23.7.94 (1)	Obs.	1·410	1·305		1·243	1·167	·1	1·037	0·934	0·857	0· 7	0·724	0·672	0·633	0·590	0·556	0·530
	Calc.	1·303	1·264		1·228	1·167	11 9	1·057	0·934	0·854	0·783	0·724	0·677	0·626	0·586	0·547	0·512
23.7.94 (2)	Obs.	1·288	1·230		1·187	1·127	1·072	1·009	0·908	0·832	0·756	0·708	0·653	0·613	0·580	0·544	0·518
	Calc.	1·254	1·214		1·187	1·127	1·076	1·002	0·914	0·828	0·766	0·710	0·655	0·613	0·572	0·534	0·502

24.7.94 (1)	Obs.	1·380	1·297		1·230	1·155	1·090	1·021	0·924	0·839	0·771	0·700	0·643	0·602	0·568	0·530	0·490
	Calc.	1·310	1·270		1·225	1·161	1·100	1·023	0·920	0·835	0·769	0·705	0·650	0·600	0·564	0·525	0·488
24.7.94 (2)	Obs.	1·356	1·269		1·215	1·146	1·086	1·021	0·919	0·839	0·763	0·699	0·653	0·602	0·568	0·531	...
	Calc.	1·300	1·253		1·215	1·151	1·091	1·011	0·912	0·829	0·762	0·704	0·649	0·602	0·558	0·519	...
24.7.94 (3)	Obs.	1·352	1·272		1·223	1·146	1·090	1·017	0·919	0·832	0·756	0·699	0·643	0·602	0·556	...	...
	Calc.	1·294	1·262		1·217	1·152	1·086	1·017	0·913	0·826	0·766	0·707	0·647	0·602	0·560	...	...
25.7.94 (1)	Obs.	1·400	1·290		1·255	1·149	1·086	1·017	0·914	0·832	0·756	0·699	0·643	0·602	0·568	0·531	0·518
	Calc.	1·311	1·263		1·226	1·151	1·099	1·007	0·914	0·825	0·760	0·697	0·643	0·602	0·556	0·516	0·48
25.7.94 (2)	Obs.	1·398	1·286		1·253	1·149	1·086	1·013	0·908	0·813	0·740	0·680	0·623	0·580	0·544	0·505	...
	Calc.	1·340	1·286		1·240	1·162	1·096	1·008	0·902	0·811	0·748	0·685	0·628	0·580	0·540	0·507	...
25.7.94 (3)	Obs.	1·371	1·269		1·217	1·140	1·079	1·004	0·903	0·813	0·740	0·672	0·633	0·580	0·544	0·518	...
	Calc.	1·300	1·252		1·213	1·141	1·083	1·004	0·900	0·818	0·747	0·689	0·635	0·584	0·544	0·508	...
27.7.94 (1)	Obs.	1·386	1·280		1·225	1·149	1·090	1·017	0·919	0·832	0·756	0·699	0·663	0·613	0·568	0·531	0·505
	Calc.	1·312	1·266		1·225	1·153	1·092	1·017	0·916	0·832	0·764	0·701	0·650	0·613	0·568	0·531	0·496
27.7.94 (2)	Obs.	1·362	1·267		1·212	1·133	1·000	0·898	0·806	0·740	0·690	0·633	0·591	0·544	0·505	0·477	...
	Calc.	1·292	1·250		1·210	1·138	·996	0·894	0·812	0·742	0·683	0·633	0·591	0·550	0·512	0·477	...
27.7.94 (3)	Obs.	1·371	1·281		1·215	1·140	1·079	1·004	0·898	0·819	0·748	0·681	0·633	0·591	0·556	0·518	...
	Calc.	1·294	1·252		1·213	1·138	1·081	·998	·898	0·813	0·752	0·687	0·635	0·588	0·553	0·518	...
30.7.94 (1)	Obs.	1·364	1·269		1·217	1·140	1·083	1·013	0·919	0·826	0·763	0·708	0·653	0·613	0·568	0·531	0·505
	Calc.	1·292	1·252		1·215	1·148	0·089	1·013	0·913	0·833	0·763	0·708	0·653	0·610	0·566	0·525	0·499
30.7.94 (2)	Obs.	1·332	1·255		1·215	1·137	1·079	1·013	0·914	0·832	0·763	0·708	0·663	0·613	0·580	0·544	0·505
	Calc.	1·274	1·232		1·196	1·141	1·081	1·013	0·920	0·833	0·769	0·715	0·658	0·611	0·573	0·542	0·507
30.7.94 (3)	Obs.	1·303	1·240		1·199	1·130	1·072	1·009	0·914	0·832	0·763	0·708	0·653	0·613	0·580	0·531	0·505
	Calc.	1·262	1·228		1·197	1·128	1·076	1·008	0·914	0·833	0·769	0·710	0·653	0·611	0·568	0·531	0·503
31.7.94 (1)	Obs.	1·238	1·196		1·158	1·100	1·045	0·987	0·898	0·819	0·748	0·708	0·653	0·602	0·568	0·531	...
	Calc.	1·222	1·196		1·160	1·100	1·050	0·989	0·895	0·820	0·758	0·700	0·643	0·602	0·568	0·525	...
31.7.94 (2)	Obs.	1·288	1·230		1·187	1·124	1·072	1·009	0·908	0·832	0·763	0·708	0·653	0·613	0·580	0·544	0·505
	Calc.	1·252	1·219		1·191	1·124	1·072	1·002	0·908	0·832	0·763	0·708	0·661	0·611	0·568	0·536	0·497
31.7.94 (3)	Obs.	1·303	1·240		1·196	1·130	1·079	1·009	0·914	0·839	0·763	0·708	0·663	0·613	0·580	0·544	0·505
	Calc.	1·290	1·240		1·204	1·150	1·088	1·013	0·917	0·839	0·769	0·710	0·656	0·611	0·570	0·534	0·495

TABLE VIII.—*Continued.*

Date.	Log. y	1	2	3	5	7	10	15	20	25	30	35	40	45	50	55
1.8.94 (1)	Obs.	1·318	1·250	1·199	1·130	1·079	1·013	0·908	0·839	0·763	0·708	0·663	0·613	0·580	0·544	0·518
	Calc.	1·280	1·237	1·199	1·137	1·083	1·012	0·915	0·836	0·766	0·710	0·659	0·615	0·578	0·540	0·500
1.8.94 (2)	Obs.	1·220	1·182	1·152	1·090	1·045	0·982	0·892	0·813	0·748	0·699	0·653	0·613	0·580	0·544	0·505
	Calc.	1·219	1·182	1·153	1·098	1·050	0·980	0·895	0·823	0·756	0·699	0·647	0·603	0·567	0·530	0·505
2.8.94 (1)	Obs.	1·310	1·253	1·204	1·133	1·079	1·013	0·914	0·826	0·763	0·708	0·663	0·613	0·580	0·544	0·518
	Calc.	1·272	1·235	1·204	1·141	1·088	1·015	0·918	0·824	0·777	0·719	0·663	0·615	0·578	0·538	0·510
2.8.94 (2)	Obs.	1·196	1·161	1·133	1·083	1·025	0·968	0·886	0·806	0·740	0·699	0·643	0·602	0·568	0·531	...
	Calc.	1·190	1·159	1·133	1·075	1·036	0·973	0·885	0·812	0·754	0·694	0·640	0·597	0·561	0·524	...
2.8.94 (3)	Obs.	1·114	1·093	1·068	1·025	0·978	0·919	0·845	0·778	0·708	0·663	0·613	0·580	0·544	0·518	0·491
	Calc.	1·116	1·093	1·068	1·023	0·980	0·921	0·845	0·778	0·718	0·663	0·617	0·578	0·539	0·505	0·482
3.8.94 (1)	Obs.	1·017	1·000	0·987	0·954	0·919	0·881	0·819	0·763	0·716	0·681	0·643	0·613	0·580	0·556	0·531
	Calc.	1·015	0·998	0·981	0·949	0·920	0·883	0·813	0·768	0·725	0·680	0·637	0·606	0·571	0·532	0·504
3.8.94 (2)	Obs.	1·377	1·276	1·217	1·170	1·079	1·004	0·898	0·813	0·740	0·690	0·633	0·591	0·544	0·518	...
	Calc.	1·304	1·257	1·217	1·146	1·086	1·004	0·900	0·821	0·748	0·689	0·632	0·588	0·549	0·511	...
3.8.94 (3)	Obs.	0·982	0·959	0·939	0·908	0·869	0·826	0·756	0·699	0·643	0·602	0·556	0·518	0·491	0·462	...
	Calc.	0·976	0·956	0·937	0·904	0·869	0·823	0·756	0·698	0·643	0·602	0·559	0·521	0·489	0·456	...
3.8.94 (4)	Obs.	1·176	1·146	1·117	1·061	1·013	0·949	0·851	0·778	0·716	0·653	0·613	0·568	0·544	0·505	...
	Calc.	1·174	1·146	1·115	1·058	1·005	0·943	0·858	0·784	0·719	0·665	0·613	0·573	0·536	0·509	...
4.8.94 (1)	Obs.	1·179	1·152	1·127	1·083	1·041	0·982	0·903	0·826	0·778	0·716	0·681	0·643	0·613	0·580	0·544
	Calc.	1·174	1·152	1·127	1·082	1·039	0·980	0·905	0·846	0·786	0·725	0·675	0·635	0·592	0·560	0·523
4.8.94 (2)	Obs.	1·133	1·111	1·090	1·045	1·009	0·954	0·881	0·813	0·748	0·708	0·663	0·623	0·591	0·556	0·518
	Calc.	1·127	1·103	1·090	1·043	1·005	0·956	0·883	0·824	0·763	0·706	0·661	0·621	0·586	0·556	0·518
4.8.94 (3)	Obs.	0·799	0·785	0·778	0·756	0·732	0·716	0·663	0·633	0·602	0·568	0·531	0·518	0·491	0·462	...
	Calc.	0·783	0·774	0·768	0·748	0·731	0·707	0·668	0·628	0·597	0·560	0·527	0·500	0·472	0·447	...
4.8.94 (4)	Obs.	0·785	0·771	0·763	0·748	0·732	0·699	0·653	0·623	0·591	0·556	0·531	0·518	0·491	0·462	...
	Calc.	0·783	0·766	0·763	0·748	0·729	0·706	0·667	0·626	0·596	0·565	0·531	0·503	0·481	0·452	...

4.8.94 (5)	Obs.	1·230	1·187		1·152	1·097	1·041	0·982	0·892	0·813	0·748	0·699	0·643	0·602	0·568	0·544	...	
	Calc.	1·207	1·178		1·148	1·092	1·039	0·980	0·891	0·814	0·758	0·701	0·646	0·606	0·568	0·530	...	
16.7.95	Obs.	1·340	1·250		1·197	1·118	1·052	0·977	0·864	0·770	0·700	0·635	0·590	0·557	0·518	...	...	
	Calc.	1·302	1·250		1·204	1·126	1·030	0·975	0·862	0·778	0·714	0·646	0·583	0·548	0·508	...	...	
17.7.95	Obs.	1·362	1·258		1·200	1·130	1·012	0·954	0·840	0·750	0·674	0·557	0·520	0·500	0·444	...	...	
	Calc.	1·342	1·268		1·216	1·120	1·046	0·952	0·820	0·742	0·674	0·613	0·560	0·510	0·475	...	...	
18.7.95	Obs.	1·350	1·248		1·184	1·100	1·030	0·945	0·820	0·730	0·683	0·602	0·512	0·462	0·413	0·398	...	
	Calc.	1·303	1·242		1·188	1·098	1·024	0·933	0·822	0·730	0·672	0·590	0·540	0·494	0·450	0·417	...	
19.7.95	Obs.	1·337	1·237		1·178	1·090	1·017	0·930	0·812	0·724	0·664	0·592	0·557	0·518	0·478	0·444	...	
	Calc.	1·285	1·220		1·173	1·084	1·015	0·928	0·821	0·724	0·662	0·602	0·555	0·510	0·470	0·434	...	
20.7.95 (1)	Obs.	1·324	1·231		1·174	1·090	1·020	0·944	0·824	0·740	0·664	0·617	0·533	0·518	...	...	...	
	Calc.	1·287	1·229		1·174	1·090	1·020	0·933	0·822	0·737	0·664	0·610	0·533	0·516	...	...	...	
20.7.95 (2)	Obs.	1·328	1·224		1·165	1·080	1·000	0·917	0·794	0·701	0·642	0·568	0·523	0·479	0·440	0·20	...	
	Calc.	1·312	1·232		1·174	1·080	0·994	0·902	0·792	0·702	0·633	0·574	0·522	0·481	0·444	0·14	...	
20.7.95 (3)	Obs.	1·324	1·239		1·164	1·080	1·003	0·920	0·800	0·700	0·624	0·580	0·532	0·479	...	...	...	
	Calc.	1·315	1·238		1·174	1·080	1·007	0·917	0·800	0·707	0·639	0·578	0·520	0·476	...	...	...	
22.7.95	Obs.	1·313	1·210		1·150	1·055	0·984	0·892	0·770	0·680	0·612	0·556	0·502	0·461	0·440	0·398	0·362	
	Calc.	1·268	1·205		1·146	1·048	0·981	0·888	0·776	0·687	0·612	0·558	0·514	0·464	0·426	0·395	0·358	
23.7.95	Obs.	1·310	1·203		1·144	1·045	0·978	0·877	0·750	0·654	0·590	0·545	0·490	0·450	0·417	0·380	0·343	
	Calc.	1·328	1·237		1·160	1·045	0·964	0·868	0·754	0·670	0·602	0·540	0·495	0·449	0·415	0·380	0·353	
26.7.95 (1)	Obs.	1·302	1·208		1·130	1·043	0·980	0·884	0·968	0·883	0·827	0·766	0·718	0·680	0·650	0·616	...	
	Calc.	1·264	1·199		1·143	1·047	0·978	0·872	0·980	0·887	0·824	0·766	0·719	0·674	0·634	0·600	...	
26.7.95 (2)	Obs.	1·298	1·192		1·122	1·022	0·938	0·844	0·716	0·643	0·580	0·520	0·478	0·432	0·380	0·344	0·323	
	Calc.	1·298	1·192		1·118	1·012	0·930	0·840	0·728	0·643	0·574	0·522	0·477	0·430	0·400	0·368	0·339	
25.7.95	Obs.	1·297	1·192		1·123	1·025	0·950	0·858	0·732	0·645	0·580	0·518	0·478	0·432	0·400	0·461	...	
	Calc.	1·272	1·190		1·128	1·022	0·946	0·852	0·743	0·652	0·569	0·512	0·481	0·431	0·394	0·469	...	
27.7.95	Obs.	1·298	1·190		1·118	1·020	0·944	0·846	0·724	0·646	0·580	0·517	0·478	0·417	0·380	...	...	
	Calc.	1·296	1·204		1·127	1·016	0·940	0·840	0·730	0·643	0·578	0·520	0·478	0·430	0·396	...	...	
9.12.95	Obs.	1·292	1·190		1·130	1·043	0·968	0·880	0·762	0·668	0·592	0·532	0·506	0·448	0·424	0·380	...	
	Calc.	1·292	1·210		1·146	1·040	0·960	0·866	0·752	0·670	0·602	0·541	0·490	0·446	0·410	0·370	...	

TABLE VIII.—*Continued.*

Date.	Log. y	1	2		3	5	7	10	15	20	25	30	35	40	45	50	55
12.12.95	Obs.	1·305	1·190		1·134	1·042	0·968	0·876	0·760	0·672	0·602	0·556	0·505	0·462	0·432	...	...
	Calc.	1·288	1·204		1·146	1·039	0·966	0·874	0·762	0·674	0·599	0·553	0·506	0·462	0·422	...	...
17.12.95	Obs.	1·111	1·072		1·042	0·976	0·930	0·850	0·760	0·690	0·638	0·580	0·544	0·506	0·462	0·440	...
	Calc.	1·110	1·072		1·037	0·981	0·928	0·860	0·768	0·693	0·638	0·578	0·527	0·486	0·450	0·418	...
18.12.95	Obs.	1·121	1·083		1·047	0·992	0·937	0·870	0·786	0·716	0·658	0·612	0·568	...	...	...	...
	Calc.	1·120	1·086		1·046	0·992	0·939	0·873	0·786	0·715	0·658	0·602	0·554	...	...	...	...
19.12.95	Obs.	0·964	0·940		0·924	0·890	0·858	0·812	0·748	0·690	0·648	0·602	0·574	0·544	...	...	...
	Calc.	0·962	0·942		0·924	0·888	0·856	0·810	0·750	0·692	0·641	0·602	0·563	0·528	...	...	...
19.12.95	Obs.	0·842	0·826		0·810	0·778	0·764	0·736	0·682	0·648	0·602	0·562	0·532	0·506	...	...	...
	Calc.	0·838	0·827		0·812	0·782	0·766	0·736	0·684	0·644	0·604	0·564	0·532	0·498	...	...	...
20.12.95 (1)	Obs.	0·716	0·708		0·701	0·688	0·674	0·654	0·622	0·594	0·564	0·536	0·510	0·483	...	...	...
	Calc.	0·713	0·704		0·699	0·687	0·673	0·653	0·622	0·590	0·563	0·537	0·509	0·484	...	...	...
20.12.95 (2)	Obs.	0·474	0·470		0·464	0·454	0·446	0·432	0·408	0·388	0·366	0·344	0·324	...	...	...	...
	Calc.	0·474	0·470		0·464	0·454	0·444	0·429	0·407	0·386	0·364	0·345	0·326	...	...	...	...
24.12.95	Obs.	0·209	0·206		0·202	0·198	0·190	0·184	0·173	0·161	0·146	0·137	0·121	0·111	0·100	...	...
	Calc.	0·207	0·203		0·201	0·197	0·190	0·185	0·176	0·162	0·149	0·136	0·122	0·112	0·099	...	...
24.12.95	Obs.	0·923	0·910		0·900	0·878	0·857	0·826	0·780	0·740	0·704	0·670	0·638	0·606	0·578	...	...
	Calc.	0·922	0·910		0·900	0·880	0·857	0·826	0·780	0·740	0·708	0·671	0·638	0·608	0·570	...	...

Dr. Peddie on Torsional Oscillations of Wires.

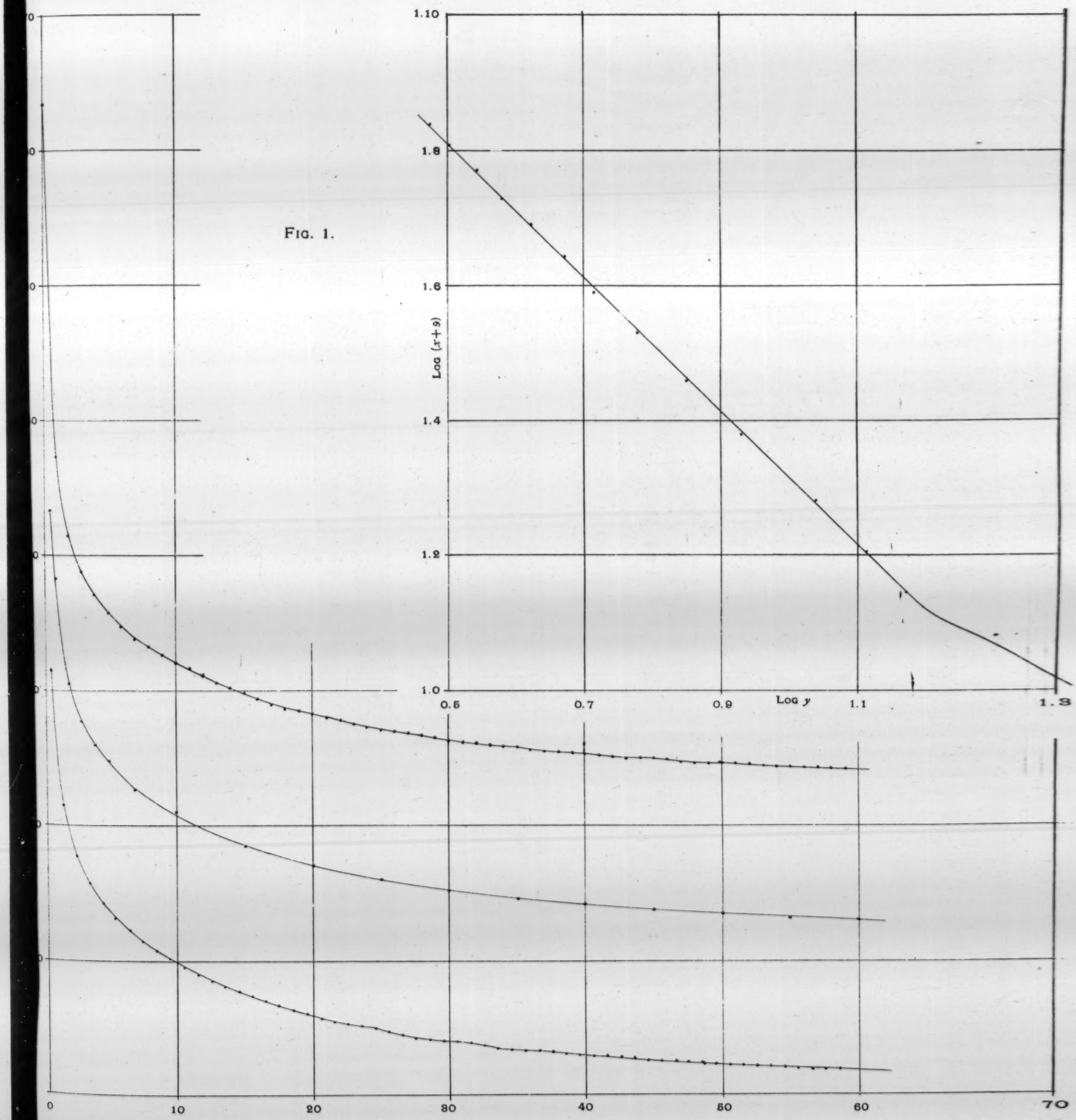


Fig. 1.

DR. PEDDIE ON TORSIONAL OSCILLATIONS OF WIRES.

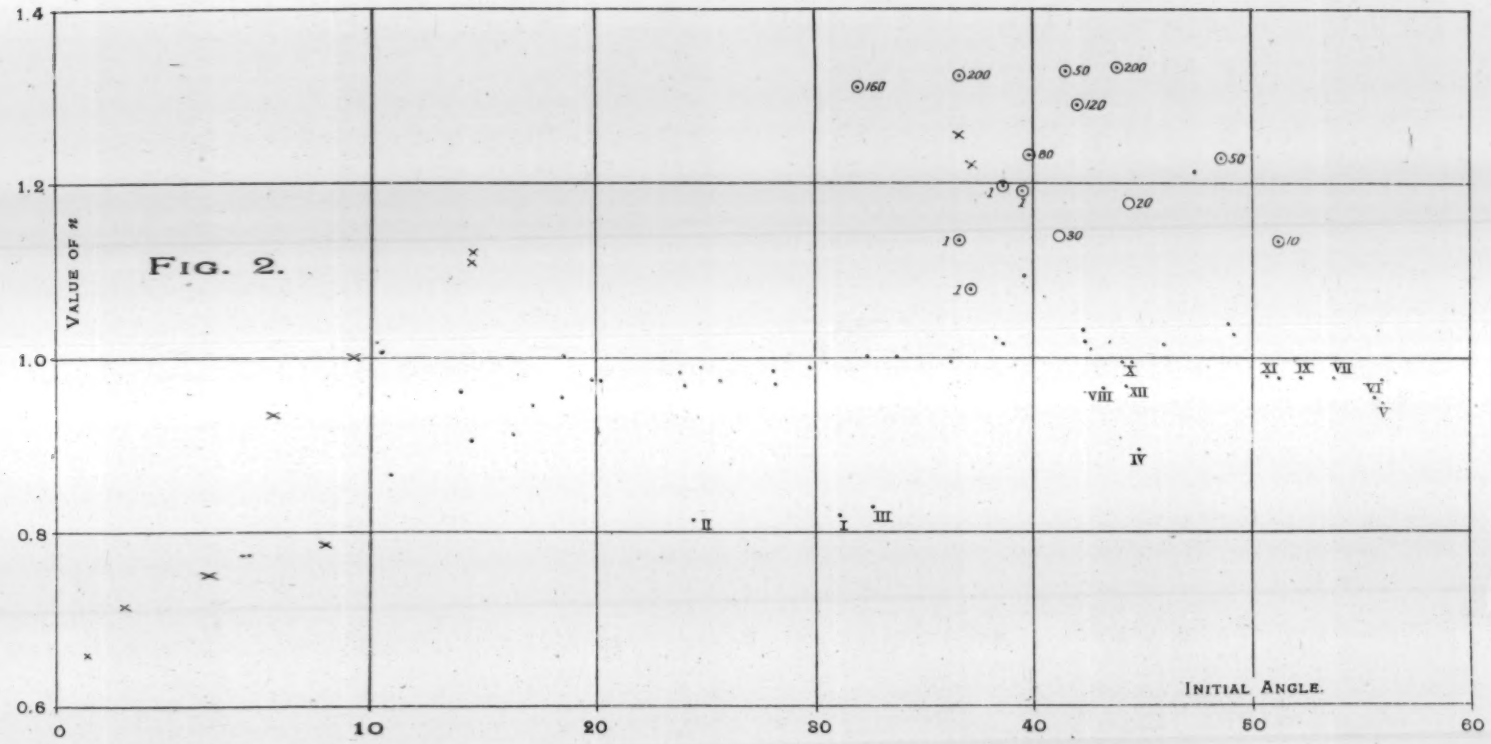


FIG. 2.

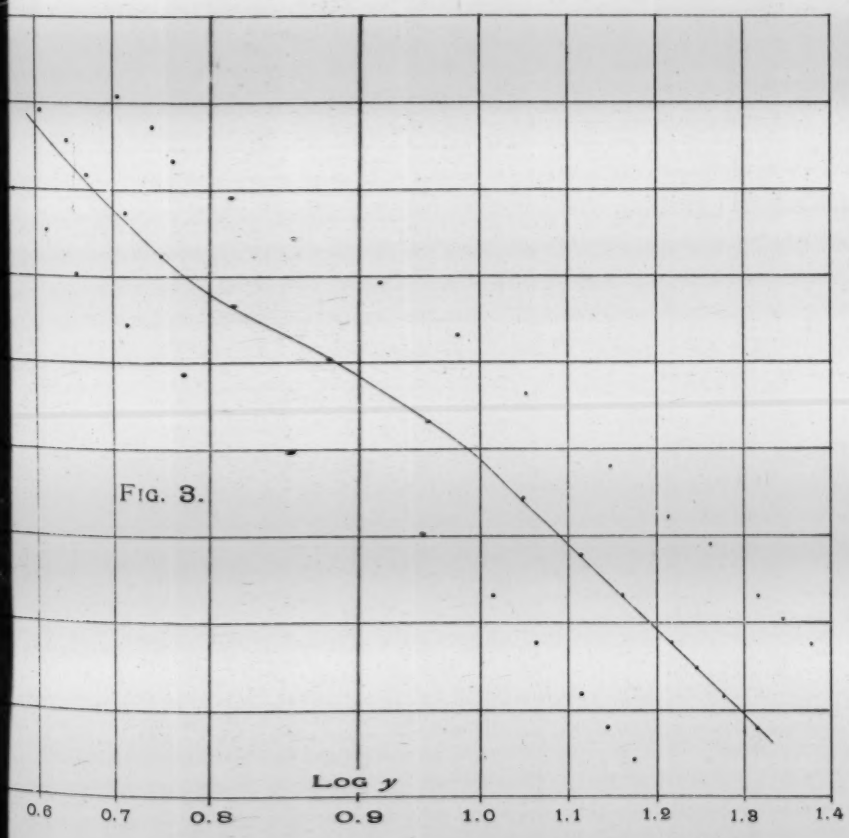


FIG. 3.

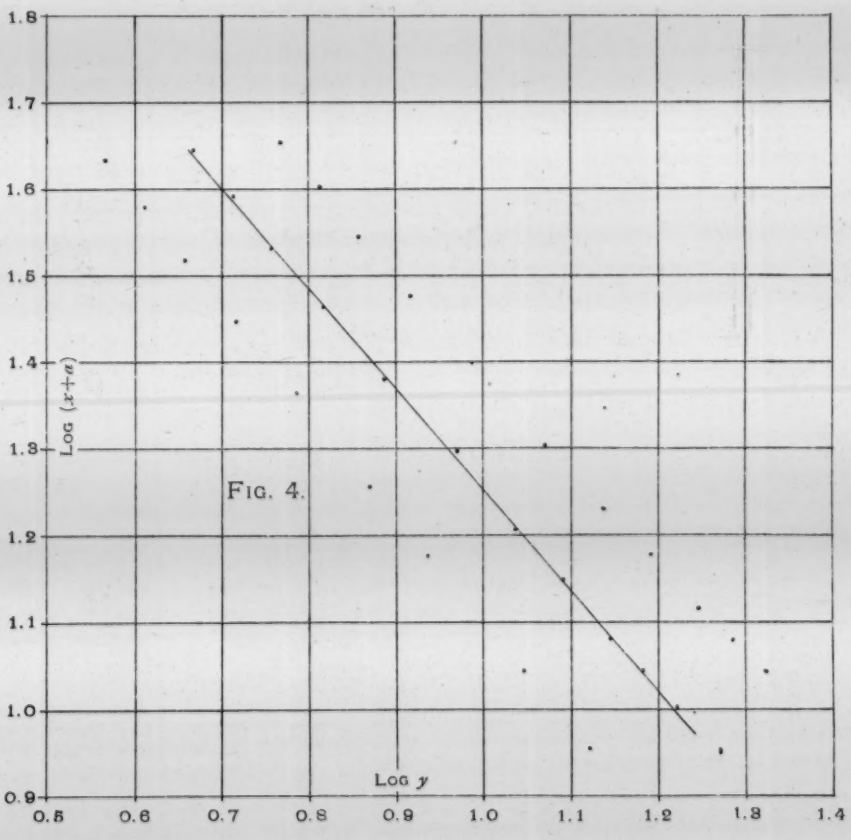


FIG. 4.

XIX.—*On the Cranial Nerves of* Chimæra monstrosa (Linn. 1754) ; *with a Discussion of the Lateral Line System, and of the Morphology of the* Chorda tympani.

By Frank J. Cole, Demonstrator and Assistant Lecturer of Zoology, University College, Liverpool. Communicated by Professor Ewart, M.D., F.R.S. (With Two Plates.)

(Read June 15, 1896.)

CONTENTS.

	PAGE
A. Introductory,	631
B. Historical,	632
C. Classification of Sensory Canals,	635
(1) General Scheme,	635
(2) The Sensory Canals one organ,	637
(3) Difficulties to above,	638
(4) Garman's Classification,	639
D. Sensory Canals of *Chimæra*,	640
E. The Eye Muscle Nerves,	642
(1) Oculo-motor,	642
(2) Patheticus,	643
(3) Abducens,	644
F. Trigeminus,	644
(1) Roots of Vth and Buccal,	644
(2) Literature,	647
G. The VIIth or "Facial Proper,"	651
H. Lateral Line System,	653
(1) Lateralis,	656
(2) Auditory,	656
(3) Literature of Facial and Lateral Line System,	656
(3*a*) Homology of Chorda tympani,	657
(3*b*) Typical hyomandibular,	662
(3*c*) Roots of Vth and VIIth,	662
J. Glossopharyngeal,	664
(1) The Gills of *Chimæra*,	664
(2) Literature,	666
K. Vagus,	666
(1) Vagus of *Chimæra* very primitive,	666
(2) Literature,	670
L. Anterior Spinal Nerves,	672
Postscript,	673
Summary,	674
Bibliography,	676

A. Introductory.

This investigation first commenced in the examination of a few special points which had arisen in connection with Professor Ewart's investigations on the Cranial Nerves and Lateral Sense Organs of Elasmobranchs. As this examination revealed facts of more interest than was expected, it occurred to me to investigate very thoroughly the whole of the cranial nerves of this animal, and to publish the results as a continuation of the work already alluded to. The research turned out to be much easier and more interesting than I had anticipated, and, as regards its cranial nerves at any rate, *Chimæra* is unrivalled among vertebrates, first, for the ease with which its nerves may be dissected, and second, for the almost ideal results that are to be obtained. The endless perplexity and mystification produced by the study of the trigeminal and facial nerves of the cartilaginous fishes,—dispelled to a very great extent, it is true, by the researches of

MARSHALL and SPENCER,—would probably have never arisen if STANNIUS had made a careful examination of the roots of the 5th and 7th nerves of his *Chimæra.** This, however, he omitted to do in the very form—in fact, as far as we know, the ONLY form—which would have repaid the investigation; and hence the embryologist stepped in and made a discovery that the anatomist had just, and only just, failed to grasp. The more important facts, therefore, relating to the cranial nerves of the Holocephali are, it is claimed, here recorded for the first time.

Professor EWART very kindly fell in with my suggestion that the work should be done at once, and placed his material at my disposal. This consisted of two specimens, one of which, the male, had already been partly dissected, and was only available for the study of the 9th and 10th cranial nerves, of which I made a very careful dissection on it; from the other, a female, I obtained the greater part of the material upon which the present paper is founded. The length of this specimen, without the lash, was 43 cms., and the distance from the anterior median canal, through the eye, to the vertical part of the lateralis canal, $7\frac{1}{4}$ cms.; whilst its depth, through the eye, was $6\frac{1}{4}$ cms., and just behind the pectoral fin, 8 cms. From material I have examined since, it seems that these two specimens were in an excellent state of preservation.

My acknowledgements are due to Professor G. B. HOWES, of the Royal College of Science, South Kensington, for the very generous assistance I received from him during the Easter vacation of 1896. Besides placing his fine collection of Holocephalan material at my disposal, on which, as far as time permitted, I verified the more important parts of the work, he procured for me, with few exceptions, the whole of the works cited in the Bibliography, which, as will be seen, was no slight service. For this and many other services I desire to return both to Professor HOWES and his demonstrator, Mr MARTIN WOODWARD, my sincere thanks. The exceptions mentioned above I was enabled to consult through the kindness of Mr B. B. WOODWARD, of the Natural History Museum, South Kensington. I further have to acknowledge much useful advice given me by Dr BEARD of Edinburgh. Finally, I am greatly indebted to my esteemed chief, Prof. W. A. HERDMAN, F.R.S., for much indulgence and advice during the progress of the work.

B. HISTORICAL.†

When one considers the interesting position of the Holocephali, and the important facts which a study of their nerves and sense organs might reasonably be expected to disclose, it is indeed surprising to find that, with the exception of a very imperfect account by STANNIUS, this portion of the anatomy of these animals has been entirely neglected. The first work on the subject was published by BRESCHET in 1838 (1), who

* STANNIUS refers to his specimen as "*Chimæra* (*Calorhynchus*) *arctica*." It is really a *Chimæra monstrosa*.

† *Chimæra monstrosa* seems to have been the earliest discovered Holocephalan, and was first described by CLUSIUS, exactly 291 years ago, under the title of *Galei genus*.

described the hearing apparatus of a large number of fishes, and amongst them of *Chimæra*. He was therefore the first to describe the important fact, that *Chimæra* differs from all other cartilaginous fishes in that a portion of the internal ear projects into the cranial cavity, and is not entirely enclosed by the auditory capsule—this constituting an important point of resemblance between the sensory apparatus of Holocephali and Teleostei. BRESCHET's work was followed in 1842 by a paper of VALENTIN's on the brain (2), and this author committed the extraordinary error of completely overlooking the thalamencephalon, together with the cerebral hemispheres and olfactory lobes, and described the former—which, as is well known, is drawn out and band-like in character—as the olfactory nerve. In the following year JOHANNES MÜLLER and R. WAGNER * (3) published a criticism of VALENTIN's paper, doubting the homologies of some of the parts, but although MÜLLER made a re-examination of the brain, he did not succeed in detecting the error mentioned above. This, however, was done in 1848 by BUSCH (5), whose somewhat inaccessible memoir, therefore, was the first accurate account of the gross anatomy of the Holocephalan brain to be published. BUSCH figured (Plate II. figs. 7, 8, and 9), and described (pp. 35–40) *Callorhynchus* as well as *Chimæra*, and one of his figures of the latter may be seen in OWEN's text book.† STANNIUS followed in 1849 with his epoch-marking work on the peripheral nervous system of fishes (6), and here we get the first account of the cranial nerves of *Chimæra*. This important study will be discussed later on, and it is only necessary to say here, that owing partly to the absence of any embryological data, and partly to an insufficient examination of the intra-cranial portions of the nerves, STANNIUS fell into serious errors, which, in spite of recent work on the subject, are being perpetuated even now. An admirable account of the advancement that had been made up to 1854, both as regards *Chimæra* and cranial nerves generally, is given by STANNIUS in his Handbuch (8), which, although it contains no new facts of importance, is still an interesting and valuable addition to the literature of the subject.‡ The next memoir demanding attention was published in 1851 by LEYDIG (7), who had investigated the anatomy of the sensory canals, and showed that the canals of the anterior extremity were intermediate between the posterior open canals and the closed canals of *Callorhynchus*, in that they were partially closed by means of imperfect rings of calcified cartilage, which brought about an approximation of the lips. He also described and figured what I shall hereafter refer to as the *compound* ampullæ of the sensory apparatus, and made some further observations on the ear. MAYER next attacked the brain in 1864 (10), and engages upon a somewhat lengthy discussion of *Chimæra*, but does not add anything

* MÜLLER refers to observations of WAGNER's, which were either of a personal character only, or for some reason or other were never published.

† *Anatomy of Vertebrates*, vol. i. p. 276, 1866.

‡ Several works appeared at about this time (*e.g.*, by Prince BONAPARTE, 1846 ; COSTA, 1852 ; and DUMÉRIL, 1865), in which the geography of the sensory canals of *Chimæra* was figured and described ; but it is not necessary to refer to them specially, since, as far as *Chimæra* is concerned, they contain little that is new and nothing of importance. DUMÉRIL gives a rough description of the ear, apparently unaware that this had previously been described by BRESCHET (1).

to the description of BUSCH, whose figures he reproduces (Pl. I. figs. 8 and 9). In 1869, or exactly 21 years after the publication of BUSCH's memoir, GEGENBAUR (13) printed, in the *Jenaische Zeitschrift*, an extract from a letter he had received from MIKLUCHO-MACLAY of Messina, in which the true nature of VALENTIN's "olfactory nerves" was independently stated, and the cerebral hemispheres and olfactory lobes re-discovered. MIKLUCHO-MACLAY was clearly unaware of BUSCH's work, and apparently so also was GEGENBAUR, whilst the latter further complicates matters by attributing to MÜLLER a discovery which he certainly never made—*i.e.*, that of the cerebral hemispheres and olfactory lobes. The next reference to *Chimæra* occurs in a suggestive paper published in 1874 by VETTER (15), in which some motor branches of the trigeminus to the muscles of the labial cartilages were described. HUBRECHT (17), in 1877, makes passing references to the sensory canals and nerves, but unfortunately follows the erroneous account of the latter given by STANNIUS. In the same year appeared a description of the brain by WILDER (18), who finds a close homology between it and the brains of most sharks and skates. No new facts, however, of any importance are added to the accounts of BUSCH and MIKLUCHO-MACLAY, and the paper is mostly concerned with the anatomy of the brain as revealed by dissection. SCHWALBE's important memoir on the ciliary ganglion (23), published in 1879, contains two figures of the nerves of *Chimæra*. This work will be fully discussed in its proper place, but I may mention now that, whilst SCHWALBE evidently regarded STANNIUS' account of the nerves as correct, he was the first to figure the roots of the VIIth, although, with STANNIUS, he regarded them as belonging to the Vth, and completely overlooked the true roots of the latter nerve. A year later, in 1880, SOLGER published an account of the histology of the sensory canals of *Chimæra* (25), in which he figures the sensory epithelium of the canals, and describes the position of the sense organs, which, anteriorly, he accurately states as being situated midway between the diamond-shaped openings. He calls the anterior semi-closed canals "secondary" and the posterior open ones "primary"—the latter, in his opinion, being more primitive. In 1881 RETZIUS re-investigated the anatomy of the ear (29), and described it in more detail than BRESCHET, whose figures he considerably improves upon. Finally GARMAN (33) described and figured the course of the canals in *Chimæra* and *Callorhynchus*, and, not having investigated the nerves, gave them names of purely local significance. I propose to discuss this method of nomenclature later on.

This concludes, as far as I am aware, the survey of all the literature relating to the nerves and sense organs of *Chimæra*. It is only necessary to add that an abstract of the present paper was published in March 1896 (69), to be followed in the following month by Mr COLLINGE's memoir on the sensory and ampullary canals (70). The latter was reviewed by me in the *Anatomischer Anzeiger* (71), and it is not necessary, therefore, that I should make any further reference to it in the present publication.

C. The Classification of Sensory Canals.

The sensory canals of fishes and amphibia may be divided into four groups, which are :—

(1) The lateral canal running from the tip of the tail forwards at the side of the body. This, just posterior to the orbit, divides into
(2) The supra-orbital canal, coursing over the eye, and
(3) The infra-orbital canal, situated under the eye.
(4) The hyomandibular or operculo-mandibular canal is a branch of the infra-orbital, and runs outwards at right angles from it.

Until comparatively recently, the most conflicting views have been held as to the innervation of these canals, and one is constantly encountering statements to the effect that the Vth cranial nerve does a great, if not the greater, part of the work. There can be no doubt therefore, in discovering the buccal nerve to be a branch of the VIIth, and not of the Vth, as had previously been believed, and further, in firmly establishing the existence of an ophthalmicus superficialis portio facialis, that Marshall and Spencer laid the foundation upon which the knowledge we now possess of the lateral line system has since been largely built.

The Vth cranial nerve, then, being excluded from the field, the way was prepared for the elucidation of the following scheme, which is founded upon the results obtained by those investigators who have made a careful and special investigation of the lateral line system :—

(1) The lateral canal and occipital or supra-temporal commissure are innervated by the lateralis division of the vagus.
(2) The supra-orbital canal is innervated by the superficial ophthalmic division of the facial.
(3) The infra-orbital canal is innervated by the buccal and otic divisions of the facial.
(4) The hyomandibular or operculo-mandibular canal is innervated by the external mandibular division of the facial.

It is thus seen that the innervation of the lateral line system comes from the VIIth and Xth nerves only, but there are apparent exceptions which will be discussed later on.

By confining ourselves to the researches of those who have paid special attention to the lateral line system, and have made a careful examination of the nerves, we find that the above scheme applies to all the classes of animals in which the system is either a permanent or temporary characteristic, *e.g.* :—

(1) Holocephali (present communication).
(2) Elasmobranchs (Ewart).

(3) Teleosts (Pollard—Siluroids, *e.g.*, *Clarias* and *Auchenaspis*).
(4) Ganoids (Allis).
(5) Dipnoi (Pinkus).
(6) Amphibia (Strong).

Although it is somewhat anticipating matters, it is necessary that this scheme should be discussed before proceeding to classify and describe the geography of the sensory canals of *Chimæra*.

First of all I may quote a passage from a valuable memoir on the cranial nerves of Amphibia by STRONG (68), who has in it contributed much to our knowledge of the lateral line system. He says that the innervation of the sensory canals has been found to be essentially the same "in *all* the forms in which they have been studied and carefully distinguished"; and further, that though there may be individual variations, yet "the roots and principal divisions and their arrangement will probably be found to hold good for all." That there is weighty evidence in favour of STRONG'S statements is obvious to any one who has made a study of the literature of the subject.

The first thing that will probably strike the reader on glancing at the above scheme, is, why should the vagus take any part in innervating the lateral line system? It is obvious that, with the exclusion from the field of all the cranial nerves except the VIIth and Xth, if the lateralis could only be shown to be connected with the other lateral line nerves, we should then have the whole of the sensory canals supplied by a single system of nerves. The lateralis used to be described as arising from the trunk of the vagus, but this condition has been found to have been an error of observation, and possibly obtains in no single fish. The fact is, as first suggested by BALFOUR, that the lateralis is quite a distinct nerve from the vagus, and has a ganglion and a separate root in front of the vagal roots, and partly in front of and partly overlapping the root of the glossopharyngeal. This condition I can vouch for in the following forms: *Chimæra*, *Raia*, *Scyllium*, *Acanthias*, *Heptanchus*, *Læmargus* and *Torpedo*.*

This fact in itself is both interesting and suggestive, tending, as it does, to show that the lateralis should not be confounded with the vagus. STRONG'S work, however, completes the case, and further shows *that the lateralis must be associated with the other lateral line nerves*, i.e., *considered a component of the VIIth cranial nerve.* STRONG shows that in Amphibia the superficial ophthalmic of the facial, the buccal, and the hyomandibular (lateral line portion) *arise from a common trunk which has its internal origin in the brain from a special nucleus—the "tuberculum acusticum," the only other cranial nerve arising from this nucleus being the lateralis.* The lateralis, then, has a totally distinct internal origin from the vagus, and that origin, moreover, is identical with the nucleus giving rise to the other lateral line nerves and to them alone. The lateralis,

* In this connection it is interesting to note EWART'S description of the root of the lateralis in *Læmargus*. He says (58, p. 74):—"The fibres which form the lateralis nerve spring from the side of the medulla, nearly in a line with the middle roots of the facial nerve; and the anterior fibres lie in front of, and on a higher level than, the roots of the glossopharyngeus." *Cp.* also STRONG (68) and AHLBORN (32).

however, is not a branch of the trunk mentioned above, but arises in close proximity to it, *i.e.*, an appreciable distance in front of and dorsal to the internal origin of the glossopharyngeal and vagus. Notwithstanding his discovery of the above important facts, STRONG still continued to include the lateralis with the vagus, and apparently did not observe that they lent valuable support to the view which I shall now proceed to develop.

The natural corollary of the above is, that the lateral line nerves form a single complete system, and are not, for example, the representatives of the seven supra-branchial nerves described by BEARD. This view was first suggested, I believe, by POLLARD (60). He says (p. 528) :—"For convenience it is best to regard the lateral line system in the adult *Clarias* as one organ *sui generis*, as much so as the auditory organ, for example, and to think of the nerves merely as branches corresponding to the various branches of the auditory nerve. They all arise from the same region of the brain, though they take different directions." Further, STRONG may be considered as implying the same when he denies the segmental character of the lateral line system, and asserts that it cannot be considered a guide to the study of the segmentation of the head.

The proof that the lateral line system is a distinct formation innervated by a single and specially developed system of nerves, is based upon the following facts :—

(1) They have a distinct and characteristic development, in so far as they are developed from the skin, and sink down into their adult positions, and are not, like the true cranial nerves, developed from the neural crest.* This is insisted on by POLLARD, who says :†—"The nerves of the lateral line system develop quite differently from the trigeminal branches. Their ganglia are derived from cells proliferating along certain tracts of the ectoderm, as shown by BEARD, FRORIEP and KUPFFER. I have followed the process myself in *Gobius*. The evidence of comparative anatomy is not less clear as to the distinctness of the lateral line nerves in fish."

(2) As far as it is known, the development of the sensory canals themselves supports this view. Thus BEARD (35) describes the supra- and infra- orbital sensory canals as arising from the splitting of a *single* sense organ. Compare BEARD'S statements in this connection on p. 115.

(3) When the lateral sense organs disappear, the *whole* of the nerves supplying them disappear also. This is completely proved by STRONG (68), who studied the natural extirpation of the lateral line system which takes place during the metamorphosis of the Amphibian tadpole. STRONG found that none whatever of the lateral line nerves persisted in the adult frog. Hence the attempts that have been made to homologise the auricular division

* The origin of the neural crest itself, as described by BEARD (43), obviously does not affect the cogency of my argument.

† "The Oral Cirri of Silurpids, and the Origin of the Head in Vertebrates," *Zool. Jahr.*, Abth. f. Morph., Bd. 8, p. 397, 1895.

of the vagus of higher vertebrates with a lateral line nerve fall to the ground.*

(4) There is a tendency on the part of the lateral line nerves to arise, both in the embryo and in the adult, by the splitting of a single trunk. STRONG found that the superficial ophthalmic, buccal and lateral line division of the hyomandibular (facial) all arose from a single trunk in Amphibia. POLLARD (60) describes facts of a similar character. For example, he finds that in several forms of Siluroids the superficial ophthalmic and buccal divisions of the VIIth arise in the adult from a single trunk. The same is described for Elasmobranch embryos by VAN WIJHE and BEARD. A partial common origin is described by EWART in *Læmargus*, whilst a more marked form will be presently described in *Chimæra*.

(5) All the lateral line nerves have a single common internal origin in the brain ("tuberculum acusticum"), from which none of the other cranial nerves arise (STRONG). This common origin, pending further investigations, must be associated with the facial nerve, but its morphological relations may not be with any of the cranial nerves. Each of the four great divisions of the system (superficial ophthalmic, buccal, external mandibular, and lateralis) may have a separate external origin from the brain, and therefore the fact that the lateralis has a separate root is of no special significance, whilst its position on the medulla points to its common internal origin with the other lateral line nerves. The connection between the lateralis and the vagus, therefore, is more apparent than real, and its relations to the vagus must have been secondarily acquired, and correspond to the confusion of the buccal nerve with the maxillary division of the Vth.†

(6) Each of the four lateral line nerves has its own ganglion, and these ganglia are quite distinct from the ganglia of the cranial nerves *sensu strictu*.

It is now necessary that the apparent exceptions to the above view should be discussed. Believing as I do that no innervation of sensory canals from the trigeminal nerve will bear investigation,—and I hardly think it will be doubted that all the evidence of any reliability points to this view,—my own statement that two sense organs of the supra-orbital canal are innervated by twigs from the profundus cannot be considered of any importance. STANNIUS first proved, and proved conclusively, that fibres from one cranial nerve may accompany the branches of another; and as Dr POLLARD remarks to me in a letter: "I should prefer to say that some nerve fibres had struck the path of the profundus but did not belong to it, just as, for instance, in Siluroids the fourth nerve

* STRONG, in fact, found that the auricular nerve of the adult was not the metamorphosed lateralis, which is surely what was to be expected, seeing that the auricular nerve consists of *somatic* fibres!

† In this connection the anastomosis of the facial with the lateralis, as described by AHLBORN in *Petromyzon* (32), acquires a special significance, as if its facial origin were special sensory, it might not unreasonably be held to be the primitive root of the lateralis. *Cp.* SPENCER, *Quart. Jour. Micros. Sci.*, 1885.

accompanies the profundus, though I think everyone would hesitate to say that the fourth nerve was a branch of the profundus." To the objection that this is rather a strained explanation of an awkward fact, I would reply: (1) That whilst it must be considered an undoubted fact that the profundus of *Chimæra does* innervate sense organs of the lateral line, yet it is the *only* case of such innervation, and probably the only authentic case of *any* such innervation from the Vth; (2) That having in view the wealth of evidence in favour of the above view of the lateral line system, one is entitled to take refuge behind the statement, that until satisfactory histological evidence is produced proving the identity of the fibres from the profundus to lateral sense organs with the trigeminal nerve, we may justly decline to believe that such identity exists.*

The other case is more difficult of explanation, and must, I fear, be permitted to stand over for the present, pending further investigation on the lines followed by STRONG. It is that the glossopharyngeal may innervate a portion of the lateral line system. This is known to obtain in Elasmobranchs (*Mustelus*, RAMSAY-WRIGHT, 34; *Læmargus*, EWART and COLE, 66), Teleosts (POLLARD, 60), and Ganoids (ALLIS, 49). I have failed to find it myself in *Chimæra*, and it is significant that STRONG failed to demonstrate it in Amphibia. On the other hand, its almost constant occurrence in Teleosts is perplexing, and POLLARD found the dorsal branch of the IXth supplying a single sense organ in many Siluroids, and further, that *this sense organ was homologous throughout all the forms examined.* POLLARD'S statements, taken together with the occurrence of this nerve in such divergent groups, seem to be fatal to any such explanation as that applied to the case of the profundus, and speculation is idle pending the production of microscopic evidence as to the origin and course of the lateral line fibres in the dorsal branch of the IXth in Teleostei.

The only case in which the origin of a dorsal branch of the glossopharyngeal supplying lateral sense organs has been carefully studied is that of *Amia*, in which some very remarkable facts, entirely supporting the view of the lateral line system advocated in the present communication, have been discovered by ALLIS (49). ALLIS finds that the dorsal branch of the glossopharyngeal of Amia *arises by a separate root from the brain, passes through a separate foramen in the skull, and has a separate ganglion more or less distinct from the ganglion on the glossopharyngeal.* The dorsal branch of *Amia*, therefore, is exactly comparable to the other four divisions of the lateral line system, each of which in the typical condition arises by a separate root. I strongly suspect that further investigation will result in disassociating a portion of this nerve (where it innervates a part of the lateral line system) from the IXth, and placing it with the other lateral line nerves. A study of its internal origin in *Amia* would go a long way towards settling the question.

It only remains now to consider the system of classification adopted by GARMAN (44). GARMAN did not devote special attention to the innervation of the canals, and hence his nomenclature has a geographical value only. This is illustrated by the fact that in

* This question is further discussed on p. 649.

Chimæra 13 canals are distinguished, and the canal supplied by the buccal nerve is divided into four portions, and further confused with a part of the hyomandibular system. The fact that these 13 canals are only innervated by four nerves must, I think, be held to break down the distinctions which GARMAN has set up. The general opinion, and the most satisfactory opinion, is, that the only scientific basis upon which accurate results are to be arrived at, is to study either the development or the adult anatomy of both canals *and* nerves, and that to divorce one from the other can only be prolific of inaccurate and misleading results. This is insisted on by EWART (58, pp. 65 and 70), who quotes GARMAN as describing 14 canals in *Læmargus*, although these 14 canals are innervated by only four nerves.

I shall therefore, in the present communication, regard the lateral line system as a single system supplied by a single and *perfectly independent* system of nerves. This system of nerves, as far as is known, must be associated with the facial or seventh cranial nerve, and may be said to consist of the following four trunks* :—

(1) Superficial ophthalmic, coursing over the eye.
(2) Buccal, coursing under the eye.
(3) Hyomandibular, coursing behind the spiracle.
(4) Lateralis, associated with the vagus.

D. THE SENSORY CANALS OF CHIMÆRA.

The fact that the lateral line system of *Chimæra* consisted of open furrows visible for the whole of their length on the surface of the animal was first described, I believe, by Prince BONAPARTE in 1846. A further description was published by COSTA in 1852, whilst DUMÉRIL, in his *Histoire naturelle des Poissons*, published in 1865, supplemented the descriptions of BONAPARTE and COSTA with an account of *Callorhynchus*, and he was therefore the first to point out the interesting difference between *Chimæra* and *Callorhynchus* in this respect; in so far as the sensory canals of the latter are formed of closed tubes and not of open furrows. LEYDIG'S work, published in 1851, on the anatomy of the sensory canals (7), has been already referred to. In 1877 HUBRECHT (17) re-figured both *Chimæra* and *Callorhynchus*, and SOLGER'S memoir on the histology of the sensory canals (25, 1880) has been noticed in my historical section. GARMAN (44) gave still further descriptions and figures of both genera in 1888, and since the publication of this work numerous descriptions and figures of the sensory canals of the Holocephali have been published in text-books and elsewhere (*e.g.*, DAY, BASHFORD DEAN and others). One memoir, however, calls for special notice, and that is the description in 1894 by GOODE and BEAN† of an important new genus of Chimæroids which these authors named

* I am purposely omitting the great recurrent facial described first by STANNIUS in *Silurus*, and recently in many *Siluroids* by POLLARD. I shall refer to it later on.

† "On *Harriotta*, a new type of Chimæroid fish from the deeper waters of the North-western Atlantic," *Proc. United States Nat. Mus.*, vol. xvii. p. 471, 1894.

Harriotta. The lateral line system of this interesting fish resembles that of *Chimæra* in practically every respect, there being only two differences worth noting. These are: (1) The elongated snout has produced modifications of both supra- and infra- orbital canals; (2) both divisions of the hyomandibular (operculo-mandibular) canal meet their fellows in the mid-ventral line. Both differences are of little importance, especially the latter, since more or less marked traces of this fusion are to be seen in *Chimæra.*

Seeing that the geography of the lateral line system of *Chimæra* has been so frequently figured and described, it would be superfluous on my part to add to those

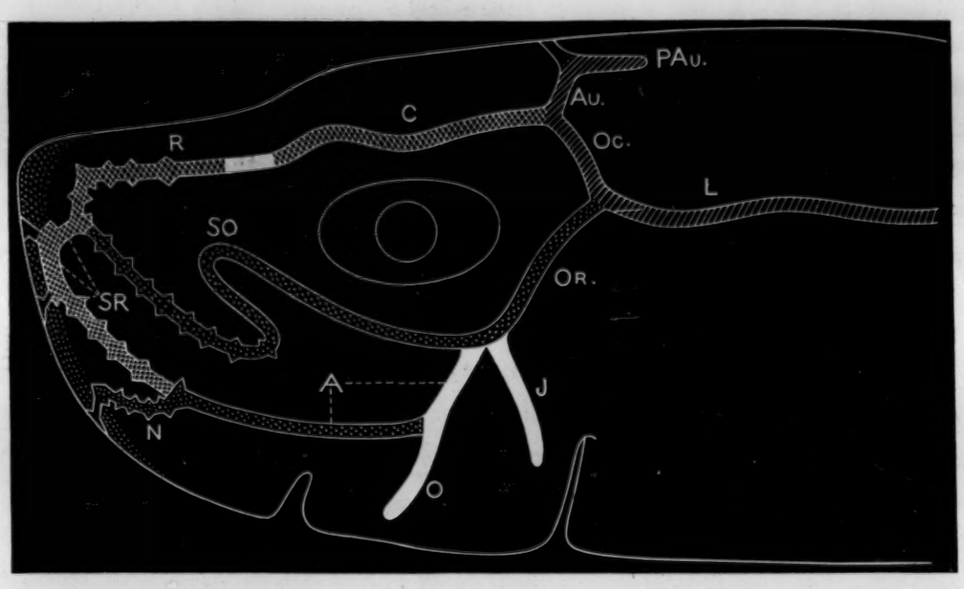


Figure of Sensory Canals of *Chimæra monstrosa*, to enable a comparison to be made between GARMAN'S nomenclature and the innervation of the system. The latter is indicated by the different kinds of shading.

(1) Supra-orbital canal (superficial ophthalmic—cross-hatched—the white segment is the portion innervated by the profundus) = cranial (C) + rostral (R) + sub-rostral (SR).
(2) Infra-orbital canal (buccal + otic—dotted) = orbital (Or) + sub-orbital (SO) + portion of angular (A) + nasal (N).
(3) Hyomandibular or Operculo-mandibular canal (external mandibular—white) = remainder of angular (A) + oral (O) + jugular (J).
(4) Lateralis canal (lateralis—oblique shading) = lateral (L) + occipital (Oc) + aural (Au) + post-aural (PAu.).

descriptions here. As, however, the innervation of the system is in this communication described for the first time, I ma· say a few words upon it in this section.

A glance at the figure and description will enable the reader to sufficiently understand the facts without any further explanation. It will then be seen what justification there is for GARMAN'S statement that "the most convenient designations for the different canals, or parts of canals, are those derived from the names of the portions of the body traversed by them, or from those of the organs near which they pass." From his description and figure it is difficult to define the boundary between the cranial and rostral canals, but the latter probably begins at that portion of the supra-orbital innervated by the profundus. A very interesting variation is noted by GARMAN, in that

he found the ventral section of the infra-orbital canal, instead of being connected with the hyomandibular, coming from the dorsal section of the infra-orbital, the latter canal therefore consisting in this specimen of a dichotomised trunk instead of two separate divisions. GARMAN further states that the oral and jugular canals may be traced across the chin to meet their fellows of the opposite side in a series of dots and splashes. This is interesting when we remember that these traces are represented by functional canals in *Harriotta*.

GARMAN points to a resemblance between the geography of the lateral line system of Holocephali and Sharks; but I do not think the resemblance is more than one of *kind*. It is extraordinary what a fundamental resemblance there is to be seen in the lateral line system of *all* Fishes. Compare in this connection the memoirs of ALLIS and EWART (49 and 58). ALLIS, by the way, considers the canals supplied by the glossopharyngeal and lateralis to belong to the infra-orbital system, which I take to be a confirmation of my view of the unity of *all* the different parts of the system.

One more observation on the anatomy of the sensory canals. These are in a semi-closed condition both anteriorly and posteriorly, owing to the presence of large numbers of imperfect calcified rings. On decalcification the lips of the canals immediately begin to gape. Anteriorly the approximation of the lips is more marked, and there occur at intervals numerous diamond-shaped openings. These openings indicate the position of the sense organs, which are situated midway between them, and the same number of openings occurs on both sides. See fig. 1.

THE CRANIAL NERVES OF CHIMÆRA.

E. THE EYE MUSCLE NERVES.

Having nothing new to describe in respect to the olfactory and optic nerves, I shall commence my description of the cranial nerves with the IIIrd.

The Oculo-motor, or Third cranial nerve.—This large nerve arises by two roots from the crus cerebri at the anterior termination of the latter just behind the pituitary body. It courses forwards and slightly downwards at the side of the pituitary body towards its foramen, which it enters as an undivided nerve. On emerging into the orbit it immediately gives off a branch to the superior rectus muscle of the eye, and at the same time bifurcates into nerves of about equal size. These two branches I shall describe as the dorsal and ventral rami of the oculo-motor, and they run respectively over and under the optic nerve. The former courses straight across the orbit dorsal to the inferior rectus and inferior oblique, and fans out on the internal rectus*; whilst the latter, after giving off a branch to the inferior rectus, pursues a somewhat parallel course, and supplies the inferior oblique.

* Rectus medialis of SCHWALBE (23).

The ciliary ganglion.—Soon after its origin the ventral or deep branch of the oculo-motor gives off a fine nerve—ultimately found to be the radix brevis (see fig. 1). This is joined by a similar nerve, arising from the profundus just distal to its ganglion, which is thus seen to be the radix longa. These two bundles unite, and at the point of union there is a swelling containing distinct ganglion cells, which will therefore be the ciliary ganglion. From the ciliary ganglion, ciliary nerves with the characteristic wavy course, of which I found two, proceed to the eye. Other ciliary nerves arise from the trunk of the profundus itself. Although this account agrees with what EWART describes in *Læmargus*, which is what one would expect to find, I prefer to leave the question open, as I only dissected the ciliary ganglion on one side, and then, owing to the parts having been disturbed by previous dissection, not as carefully as I could have wished.

Literature.—The IIIrd nerve of *Chimæra* is figured but not described by STANNIUS (6, Taf. I.). This author, however, did not figure the roots, nor the branch to the inferior rectus, and, further, was erroneous in making the profundus nerve enter the orbit by the same foramen. SCHWALBE also (23) gives a similar figure, and evidently follows STANNIUS, in so far as he too neither describes nor figures the abducens.

When I wrote my preliminary paper I was not aware that the ciliary ganglion of *Chimæra* had already been described by SCHWALBE (23). Having since that time read SCHWALBE's important memoir, I find that he gives two figures of *Chimæra*, and there is also a short description in the text. Fig. 3, Taf. XII. is a magnified view of the ciliary ganglion, whilst fig. 12, Taf. XIII. shows the nerves of the orbit and the exact position of the ganglion. SCHWALBE states that the ganglion is situated on the ventral ramus of the oculo-motor at the base of a ciliary nerve, and 9 mm. distal to the spot where the branch of the ventral ramus to the inferior rectus muscle is given off, and is visible as a distinct swelling. (The position of the ganglion, with its ciliary nerve, is shown in fig. 1). I accordingly mounted the whole of the ventral ramus of the oculo-motor on a slide, and found that whilst there was certainly no swelling, or any traces of one, a few ganglion cells (not more than 20) were situated on the anterior edge of the nerve at the base of a ciliary twig, and at the precise spot mentioned by SCHWALBE. Whether SCHWALBE's ganglion and my own are both present must be left for future investigation to determine, but I may mention that KRAUSE* believed in the existence of two ciliary ganglia, and BEARD (39, p. 575) says: "from what one sees in sharks, a division of the ciliary ganglion into two ganglia in some cases is not out of question." The latter author, however, describes the ciliary ganglion as being situated on the inferior oblique division of the oculo-motor, thus giving support to SCHWALBE's account, whilst EWART's observations (57) go to show that a double ciliary ganglion is not improbable.

The Patheticus, or Fourth cranial nerve.—This arises, as in all vertebrates, from the anterior extremity of the roof of the Sylvian aqueduct, or valve of VIEUSSENS, and

* *Morph. Jahr.*, Bd. vii., 1880.

runs upwards and outwards in the vertical fissure separating the ventral portion of the cerebellum from the optic lobe. On emerging from this fissure it courses upwards and forwards, and eventually reaches the orbit under cover of the superficial ophthalmic of the VIIth. It is obscured by the latter for the greater part of its course, but finally takes a dorsal curve, and, appearing above the superficial ophthalmic, is seen to become embedded in the superior oblique muscle of the eye.

The Abducens, or sixth cranial nerve, arises by six rootlets, one of which is conspicuous by its size, from the ventral pyramids of the medulla, at a level slightly behind the dorsal root of the VIIth and a little in front of the root of the glosso-pharyngeal. These rootlets may be traced almost on to the mid-ventral line, and the nerve itself courses in the cranial cavity forwards and slightly downwards, and passes under the roots of the Vth and VIIth, being closely applied to the roots of the Vth. It eventually emerges into the orbit by a foramen hidden by the Vth and VIIth trunks, and slightly anterior to that giving exit to these latter nerves. Once in the orbit, it passes immediately into the external rectus muscle, which it supplies.

F. The Trigeminus, or Fifth Cranial Nerve.

Roots.—This nerve, which in *Chimæra* is in a very primitive condition, being quite distinct from the facial, arises by two closely applied roots from the side of the medulla, under cover and completely obscured by the roots of the buccal division of the facial. These roots are shown separately in fig. 3, the position only of the roots of the Vth being indicated in fig. 1. The roots of the trigeminus have, of course, no connection with the so-called trigeminal lobe. The anterior root is smaller than the posterior; and although the profundus arises from the anterior margin of the main trunk of the trigeminus, yet it could not be separated from it, and the anterior root cannot, therefore, on anatomical grounds, be considered the root of the profundus in *Chimæra*. The root thus formed passes through the same foramen in the skull that gives exit to the buccal division of the facial. The latter lies over and obscures the root of the fifth, and it is only after the nerves have emerged into the orbit that the Vth can be seen, when it may be distinguished by its anterior border lying in front of the buccal. Immediately after entering the orbit the trigeminus expands into the large Gasserian ganglion.

Roots of Vth and buccal.—The main trunk of the Vth, as before stated, enters the orbit accompanied by the buccal division of the facial. Two bundles, as figured by Stannius, may then be distinguished—an anterior and a posterior, but soon afterwards the anterior comes to lie under the posterior. The anterior bundle is the main trunk of the trigeminus, whilst the posterior is almost entirely made up of the buccal nerve. There is this complication: a fairly large bundle leaves the Vth and accompanies the VIIth. This bundle divides into two—a smaller and a larger. The smaller accompanies the inner buccal (one of the divisions of the buccal) and could not be traced.

The larger accompanies one of the divisions of the outer buccal and has the following distribution:—(1) part of it accompanies the outer buccal; (2) just after leaving the orbit a few twigs of it leave the outer buccal and anastomose with the maxillary division of the Vth (fig. 1, V^s); (3) some very fine twigs (fig. 1, B^5) by a long course either reach the levator of the upper lip, or join with the maxillary in that region. The above constitutes the *only* confusion or mingling between the facial and trigeminal nerves of *Chimæra* (see figs. 1 and 3).

Branches.—I distinguish five branches of the trigeminal of *Chimæra*, as follows:—

(*a*) Profundus
(*b*) Superficial ophthalmic } "Dorsal" sensory branches.
(*c*) Maxillary (præ-branchial).
(*d*) Mandibular (post-branchial).
(*e*) Pharyngeal or visceral.

(*a*) *Profundus.*—This nerve, which represents the non-ganglionated nasal nerve of man, is one of the most interesting nerves in *Chimæra*. It has a most undoubted origin from the trunk of the trigeminus, and cannot be separated or dissected away from it. I am therefore, in the absence of definite proof to the contrary, describing it as a branch of the Vth. It arises from the main trunk somewhat proximal to the Gasserian ganglion, and soon after expands to form the profundus or "mesocephalic" ganglion. It then courses forwards and upwards under the superior and internal recti and superior oblique straight across the orbit, first giving off a twig to the ciliary ganglion. When about two-thirds across it gives off a small but conspicuous branch (which may immediately divide into two); and this branch, running in a canal bored in the cartilage of the cranium, passes over the superficial ophthalmic of the facial, and eventually reaches the skin in front of the orbital region. Here, after giving off several twigs to the skin, it was eventually traced with much difficulty through a tough fibrous tissue, *and found to innervate two sense organs of the supra-orbital canal* (marked green in fig. 1). This was seen in both my specimens.

Passing on, the profundus enters the cartilage of the cranium, and, still in the cartilage, courses upwards to pass over and become wrapped round the ventral surface of the superficial ophthalmic of the facial. It can be separated from this for a short distance, but finally becomes inseparably fused with it. After the profundus had become opposed to the facial, but arising distinctly from the profundus, a thin nerve is observed to separate out, and to run straight down so close to its fellow of the opposite side that both may be dissected at the same time. This interesting nerve is found, after a very long course, to break up on the outer surface of the inner wall of the nostril. From my notes, I must have regarded this as a *sensory* nerve, but its origin and distribution make it exceedingly probable that it corresponds to the *motor* division of the profundus found in Cyclostomes. Possibly, further investigation will establish the motor character of this nerve in *Chimæra*.

(*b*) *Superficial ophthalmic.**—This nerve is of exceptional interest, since it does not fuse with the nerve of the same name from the VIIth, and its distribution may therefore be ascertained without any of the doubt necessarily attached to its distribution in Elasmobranch fishes. It arises in the orbit from the Gasserian ganglion, and courses straight upwards, and, after crossing the superficial ophthalmic of the VIIth, runs straight forwards, above the latter, to be distributed to the skin over and in front of the orbital region. We may therefore conclude with certainty that this branch of the Vth does not innervate any sense organs of the lateral line.

The following variations of this nerve were noticed (my two specimens may be termed respectively A and B):—

(1) May be quite distinct from the superficial ophthalmic of the VIIth, as on left side of A.

(2) May send, as it passes over it, two very small bundles of fibres to the facial nerve above, as on right side of A.

(3) May completely fuse with the facial, as on left side of B (right not investigated). Figured in this condition by STANNIUS.

From material I have since examined, and which was kindly placed at my disposal by Professor G. B. HOWES, I am inclined to believe that 1 and 2 represent the normal condition. 3 I have only seen once, but it is figured and referred to by STANNIUS as an anastomosis between two divisions of the Vth (*i.e.*, his Vth). In a dissection of the nerves of *Callorhynchus* which Professor HOWES has in his laboratory, no such connection between the Vth and VIIth is to be seen. 3, of course, represents the condition found in Elasmobranchs.

Maxillary and mandibular.—The Vth divides into maxillary and mandibular branches at a level slightly in front of the optic foramen. The mandibular, as figured by STANNIUS, dips down at once. There is a large nerve given off at the same place, which seems to come from the maxillary, but which, when dissected along carefully, is found to arise mostly from the mandibular. It courses straight forwards along the floor of the orbit, and becomes buried in the expanded dorsal base of the masseter muscle of the lower jaw, of which it constitutes the principal nerve supply.

(*c*) *Maxillary.*—This nerve, whilst in the orbit, gives off a posterior motor branch, and then, leaving the orbit, sends two or three branches posteriorly to the masseter. It then receives the twigs from the outer buccal previously described, and courses straight down towards the upper jaw, which, as is well known, is in *Chimæra* fused with the cranium. Before, however, reaching the lower jaw, it gives off several motor branches from its posterior border. Arrived at the jaw, it dips down suddenly, but, before doing so, sends numerous twigs to the levator of the upper lip. It then dips down under the

* According to DIXON (*infra*), the superficial ophthalmic of the Vth of fishes possibly represents the frontal nerve of mammals.

labial cartilages, and a fairly large bundle, leaving the main nerve, fans out on the nasal sac, and, running over it, its twigs after a long course end in muscles in the immediate vicinity of the external nostrils—some being continued right on to the mid-ventral line, and all terminating near it. The greater part of the maxillary, however, consisting of three bundles, dips down and curves round under a large muscle attached to the angle of the upper jaw. The largest one is the pharyngeal or visceral, and will be described separately later on. Of the two others, one pursued a difficult course and was lost, whilst the other diverged from the pharyngeal on its ventral side, and divided into two. Both of these bundles went straight on to the upper jaw, and pierced it laterally near the dorsal extremity of the lateral set of teeth. They were too fine to be traced through the jaw, but were probably continued on to the mouth.

(*d*) *Mandibular.*—From its origin runs straight down and courses a little behind the lower jaw. On its way down it gives off numerous branches, mostly to the masseter, but some of them accompany the main nerve, and, after a long course, supply the superficial muscles of the ventral region. These are given off posteriorly. There are also several fine posterior twigs, which leave the mandibular just outside the orbit, and end in a relatively small accessory of the masseter attached to the ventral edge of the orbit. A deep motor branch also leaves the anterior edge of the mandibular, just outside the orbit. Not far from the mid-ventral line, the mandibular divides into a loose bundle, and three fairly large nerves. The bundle fans out on the muscles of the lower lip, and the larger portions of it terminate close on the mid-ventral line. The three nerves curve round and under a corresponding muscle to that which the similar branch of the maxillary curved round, and, after a long course very difficult to dissect, ultimately united on the mandibular bar. The nerve thus formed coursed along the surface of the bar until reaching the mid-ventral line, where it broke up and disappeared in the substance of the bar. The ramifications were too fine to be traced any further, but they possibly found their way on to the mouth.

(*e*) *Pharyngeal or Visceral.*—This nerve, after its origin (described in the section on the maxillary), coursed straight backwards, getting deeper and deeper. It passed deep under the two masseter muscles, and afterwards began to come upwards again. Having reached the lower jaw it passed, after a long course, on to the pharynx (*i.e.*, mouth) at the point where the lower jaw articulated with the skull. It was not traced far on to the pharynx, having by this time thinned very considerably, but there could be no doubt that it innervated a portion of the mucous membrane just inside the mouth.

Literature.—Stannius figures the Vth nerve of *Chimæra*; but as there is only one short paragraph of description, and as, further, he describes the superficial ophthalmic and buccal divisions of the lateral line system as belonging to the Vth, his account of it is somewhat unsatisfactory. There cannot, I think, be any doubt that Stannius simply removed the eye of his *Chimæra*, and studied the peripheral distribution *only* of the nerves

thereby exposed. He makes no reference to *Chimæra* in his admirable section on the roots of the Vth and VIIth (p. 20); and had he investigated them, we must, I think, have had an accurate description of them from him. Otherwise, his statements concerning the root of the glosso-pharyngeal, and his oversight of such an important and obvious nerve as the chorda tympani, and the still more obvious root of the trigeminal, cannot be explained.

STANNIUS figures but does not describe the profundus, superficial ophthalmic, and maxillary divisions of the Vth. With regard to the first, he makes it enter the orbit by a different foramen from the Vth and buccal, which is, as before explained, erroneous. A twig is referred to as the "long ciliary," but not further mentioned; and he failed to see the origin of the branch to the supra-orbital canal. The superficial ophthalmic is correctly figured, and in his specimen fused with the ophthalmic of the facial; but as he regarded the latter as a branch of the Vth, it is simply referred to as an anastomosis between two divisions of the Vth. The maxillary ("superior maxillary" of STANNIUS) need only be briefly mentioned. Two of the Vth elements accompanying the VIIth are shown (both unlettered), one leaving the buccal and coursing downwards over the masseter (fig. 1, B^5 ?), the other leaving the outer buccal and joining with the maxillary (V^8 ?). The mandibular ("inferior maxillary" of STANNIUS) is partly figured and briefly described. The large nerve to the expanded base of the masseter is also shown in the plate, but neither lettered, nor referred to in the explanation. It will be seen that STANNIUS' description of the mandibular (p. 46), which I reproduce below, agrees largely with mine; an important addition however being, that he describes and figures an anastomosis with the external mandibular (facial), which I can independently confirm :—

"Bei *Chimæra* theilt sich der R. maxillaris inferior am Augenhöhlenrande in vordere und hintere Zweige. Jene verlaufen am Boden der knorpeligen Augenhöhle schräg vorwärts und erstrecken sich grossentheils unter der Haut zur weichen Schnauze, wo sie auch Verbindungen mit Zweigen des R. buccalis eingehen. Ein Zweig is auch für die Gegend der Zwischen Oberkiefer und Unterkiefer gelegenen Labialknorpel, für deren Muskulatur und für die innere Seitenwand der Mundhöhle bestimmt.—Mehre Zweige treten in die beiden Portionem des Kiefermuskels.—Ein anderer Ast erstreckt sich zu dem grossen accessorischen Unterkieferknorpel, gelangt zum Unterkiefer, geht Verbindungen ein mit Zweigen vom R. mandibularis N. facialis, vertheilt sich in die Muskulatur der accessorischen Knorpel und endet an der Haut der Unterlippe."

PINKUS (67) describes the Vth nerve of *Protopterus* as consisting of the following branches :—

(1) Superficial ophthalmic.
(2) Profundus.
(3) Maxillary { (3*a*) Superior maxillary. (3*b*) Inferior maxillary.

The profundus is in an interesting condition, since it does not fuse with the superficial ophthalmic of either Vth or VIIth. Its cutaneous distribution is therefore an

ascertained fact, and not a surmise. The superior maxillary divides into two. One of these branches unites with the superficial ophthalmic of the Vth, whilst the ventral division has the course and relations of a maxillary nerve. Further, 3*a* seems to send some fibres to the VIIth such as I have described in *Chimæra*. The inferior maxillary is, of course, the mandibular.

In Amphibia, STRONG (68) describes the Vth nerve as follows :—

(1) Ophthalmic
(2) Maxillo-mandibular { (2*a*) maxillary } = cutaneous.
(2*b*) mandibular = cutaneous + motor.

The geography of the maxillary and mandibular is that of præ-and post-branchial nerves. STRONG also describes three "accessory cutaneous" branches, two of which spring from the root of 1, whilst the other arises from 2. All of them, however, more or less enter into relations with the *lateral line divisions of the VIIth*, and therefore exactly correspond to the bundles I found in *Chimæra* leaving the Vth and accompanying the buccal division of the VIIth. It is hence important to note that STRONG's "accessory" branches do *not* supply lateral sense organs, but are cutaneous sensory nerves. The Gasserian ganglion was found to be double, and consisted of an ophthalmic portion and a maxillo-mandibular portion.

According to EWART (51), the profundus of *Læmargus* arises by several rootlets immediately in front of the main root of the Vth, and these rootlets he regards as equivalent to the small anterior non-ganglionated root of MARSHALL and SPENCER (28). This, as STRONG points out, is no doubt the case; but, as before stated, I have been unable in *Chimæra* to connect the profundus with this anterior root. According to all reliable authority, the profundus is a cutaneous sensory nerve; and ALLIS (49) states, further, that in *Amia* it fuses with the superficial ophthalmic of the Vth. The latter statement is interesting, when we remember that in *Chimæra*, as well as in other cartilaginous fishes, the fusion is with the ophthalmic of the VIIth. Regarding the twigs from the profundus to the supra-orbital canal, and my explanation thereof given on p. 638, STANNIUS (pp. 18, 19, and 20) points to several cases of one nerve or a branch of a nerve accompanying another, and considers that it must be looked upon as mere juxtaposition, and not that the accompanying nerve is a branch of the nerve which it accompanies. He cites as an example the fourth nerve of several fishes, which is known to accompany the ophthalmicus profundus. POLLARD confirms this statement, and adds *Clarias* to STANNIUS' list. POLLARD elsewhere remarks;*—"Thus we see that the fundamental grounds for determining the homology of nerves are (1) origin from homologous nerve cells; (2) terminal distribution to definite structures. The course of the fibres is of less importance." In the same memoir (p. 398), POLLARD refers to the motor division of the profundus found in the Cyclostomata. He says :—"The motor fibres supply muscles attached to and working the nasal tube, and belonging

* *Oral Cirri*, p. 397.

to the tentacular system." As stated above, I believe this nerve is represented in *Chimæra*.

SCHWALBE (23) first discovered that there were *two* superficial ophthalmics, but did not assign each to its proper nerve. This, however, was very clearly pointed out by MARSHALL (30). SCHWALBE only saw the ophthalmic of the VIIth in *Chimæra*, and, further, overlooked the true roots of the Vth. In *Læmargus*, EWART (58, p. 75) describes the ophthalmic of the Vth as follows:—"More or less distinct in sharks, the superficial ophthalmic of the trigeminal in rays consists of very few fibres, which, on leaving the trigeminal, at once more or less completely unite with the superficial ophthalmic of the facial." In this connection, and to avoid confusion, it is important to remember POLLARD'S statement *re* the profundus of *Callicthys*. He says:*—"An ophthalmicus profundus is only represented by certain fibres running in the course of the ramus ophthalmicus superficialis of the facial." The superficial ophthalmic of the Vth is not exactly represented in Amphibia, and WILDER (62) and STRONG (68) consider that the large ophthalmic division of the trigeminus found in this group = the superficial ophth. + profundus of fishes. If this be the case, the connection between the profundus and Vth will have reached its highest possible limit.

As I have previously pointed out, the labials of *Chimæra* and the innervation of their muscles have been described by VETTER (15). He distinguishes four labial muscles, as follows:—

(1) Anterior labial.
(2) Posterior labial.
(3 and 4) The two divisions of the levator anguli oris.

It is difficult, however, to identify VETTER'S nerves with my own, beyond that the innervation comes from the maxillary (*possibly* from the motor (?) branch of the profundus), as, unfortunately, I was not acquainted with VETTER'S memoir at the time of making my dissections, and have not access to it at the time of writing. I am compelled, therefore, to refer readers interested in the subject to the original memoir itself.

Visceral branches going to the mouth from the maxillary and mandibular divisions of the Vth have been found in Amphibia by STRONG (68), and evidently correspond to the similar branches I have described above in *Chimæra*. I was only successful, however, in tracing a maxillary bundle on to the mouth.

THE FACIAL, OR SEVENTH CRANIAL NERVE.

I propose to consider this nerve in two sections, which will be described as (1) the Facial Proper, and (2) the Lateral Line Nerves. With the latter I include the auditory or eighth cranial nerve. The nerves included in (1) are those which represent the facial in higher vertebrates, whilst the lateral line nerves are held to be a perfectly independent

* *Oral Cirri*, p. 394.

series of nerves, associated, however, with the VIIth, but having no representatives whatever in animals devoid of lateral sense organs.

G. The Facial Proper.

It is first necessary to explain the precise meaning I assign to certain terms. The word 'hyomandibular' is usually applied to a stout post-spiracular nerve, consisting roughly of a portion of the lateral line system + the main trunk of the facial nerve properly so-called, or 'facial proper.' Although it seems to me unwise to include two widely different nerves under one term, simply because for a time they happen to pursue a similar course, the term 'hyomandibular' has passed into such general use that it cannot be rejected now. I shall therefore continue to use the term 'hyomandibular' as including both the lateral line and facial proper systems. The lateral line division, with its large nerve going to the hyoid group of ampullæ, I shall describe as the external mandibular,—a name given to it, I believe, by Stannius, and used by most writers on cranial nerves since his time. The remaining division, or facial *sensu strictu*, which Ewart (57) has recently called the 'palato-facial,' I shall refer to as the 'facial proper.' This is an old term of Ewart's, and is, I think, more suggestive that his 'palato-facial.' As, however, I omitted to resolve the hyomandibular into its two constituents, I am obliged, until these two constituents separate out, to consider it as a whole.

The hyomandibular arises from the medulla by a separate ventral root in front of the root of the superficial ophthalmic.* Before leaving the cranial cavity it receives a large bundle of fibres from the root of the buccal, and may, therefore, be said to have both dorsal and ventral roots. Whilst passing through the cranium it expands into the large hyomandibular ganglion, which was not resolved into lateral-line and facial-proper portions, but which, I believe, could thus have been resolved. On entering the orbit, the large palatine nerve is immediately given off; and this, on being teased, was found to have a clump of nerve-cells at its base. Arising at the very base of the latter is another and important nerve—the chorda tympani, or præ-branchial division of the VIIth. The hyomandibular soon after obliquely pierces the cranium and passes straight downwards, giving off, however, a few superficial motor fibres from its posterior edge. Arrived at about the level of the dorsal extremity of the first gill cleft, the hyomandibular divides into four trunks, which are from before backwards:—

(A) External mandibular (anterius).
(B) Facial proper (a) } = mainly motor = post-branchial division of VIIth.
(C) Facial proper (b) }
(D) External mandibular (posterius).

B is to a large extent hidden by A, C, D. A and D I shall, of course, describe in my next section (H).

* Figs. 1 and 3 should be consulted when reading this section.

We are now in a position to describe in order the branches of the facial proper. These are :—

(1) Dorsal sensory branch (wanting).
(2) Pharyngeal or visceral (= palatine).
(3) Præ-branchial (= chorda tympani—see *Literature*) } Spiracle wanting.*
(4) Post-branchial (= B + C above). }

(2) *Palatine.*—Pierces the cartilage of the cranium (see figs. 1 and 3), and runs obliquely through it on to the external wall of the pharynx. It then courses forwards and downwards, giving off a few pharyngeal branches to the roof of the mouth on its way down, and finally passes (accompanied by its fellow of the opposite side) *between* and *ventral* to the two nasal sacks, to be distributed to the teeth of the upper jaw—curving slightly backwards to do this. (The teeth are inserted somewhat deeply into the jaw.)

(3) *Chorda tympani.*—My reasons for considering the præ-branchial division of the VIIth of fishes to be the homologue of the chorda tympani of mammals are stated in the discussion of the Literature. The chorda of *Chimæra*, like the palatine, pierces the cartilage of the cranium, and, running obliquely through it, reaches the external wall of the pharynx. Arrived there, it courses straight down towards the lower jaw, giving off several pharyngeal branches anteriorly and posteriorly. At about half-way down, it receives an anastomosing branch from the facial proper B (see below). At the lower jaw it divides into several bundles, of which two are distinguishable as being of larger size. The smaller bundles are mainly distributed to the outer wall of the pharynx, but the two larger ones, after edging the lower jaw, dip under it, and are continued on to the inner wall of the pharynx, where they break up and *are distributed to the ventral portion of the pharynx* just inside the aperture of the mouth, as far as the mid-ventral line.

(4*a*) *Post-branchial* B†—This divides into two branches, the larger of which itself divides into two. We thus get three nerves as follows :—

(*a*) = Portion of "Ramus opercularis." This is the main branch, and both (*b*) and (*c*) spring from it.

(*b*) Anastomoses with the chorda tympani.

(*c*) To the extensor of the hyoid arch.

(*a*) First of all gives off (*b*), and then dips down and runs under the divisions of the hyomandibular lettered A C D above. Coursing almost straight downwards, but slightly forwards, it reaches the *inner* face of the muscle supplied by the post-branchial C, hence lying internal to the latter, but in front of it. After this point it has a triple distribution, of which one is the branch *c*. The other two are as follows : one passes on to the internal face of the muscle supplied by post-branchial C, and this plexus is given

* I believe a minute spiracle, such as, for example, that in *Lamna cornubica*, could be demonstrated in *Chimæra* if the necessary material were forthcoming.

† See above. Refers to the second of the four divisions of the hyomandibular.

off posteriorly; the other, which is the direct continuation of the nerve after giving off the above plexus, comes up to the surface and courses over the *outer* surface of the same muscle, and supplies its ventral portion, the dorsal moiety being supplied by the post-branchial C.

(*b*) Given off shortly after the origin of (*a*). It dips down and runs forwards and downwards, and, after a somewhat extended course, *anastomoses with the chorda tympani.*

(*c*) Origin described above. Runs downwards and forwards, *and becomes embedded in the extensor muscle of the hyoid arch,—i.e.*, the muscle which draws the arch forwards, and thus increases the width of the cleft.

(4*b*) *Post-branchial* C.*—This nerve, which = the remainder of the 'ramus opercularis,' soon divides into two main branches, both of which course straight downwards, and break up to form an elaborate plexus. This plexus is continued round to the mid-ventral line, and lies mostly over the anterior gill clefts. It supplies the superficial muscles (1) of the opercular fold, and (2) of the body wall overlying the gill clefts in front of the opercular fold, and between the latter and the mouth.

My reasons for describing the nerves 4*a* and 4*b* as being equivalent to the post-branchial division of the VIIth, are, I think, obvious enough. The post-branchial of the facial should, as is well known, course along the anterior edge of the hyoid arch, and supply its muscles; and since the opercular fold of *Chimæra* is associated with the hyoid arch, and is supported by cartilages borne on that arch, I think it will be admitted that these two nerves fulfil the requirements of the above definition. The facial nerve of *Chimæra*, therefore, despite the absence (?) of the spiracle, only wants a dorsal sensory branch to be comparable to the other branchial nerves.

H. The Lateral Line Nerves.

I distinguish in this system the following five nerves:—

(1) Superficial ophthalmic.
(2) Buccal.
(3) External mandibular.
(4) Lateralis.
(5) Auditory or 'eighth' cranial nerve.

(1) *Superficial ophthalmic.*—Arises from the medulla by a large ventral root situated behind the root of the hyomandibular, and below and behind the root of the auditory (see figs. 1 and 3). This root has been figured by Schwalbe (23). It courses upwards and forwards, passing *over* the root of the buccal nerve. After it has passed the buccal it receives a large bundle of fibres from the anterior edge of the latter, so that the superficial ophthalmic may be said to have both dorsal and ventral roots. There is a triangular space inclosed by the root of the buccal and the dorsal and ventral roots of

* The 'internal mandibular' (with post-branchial B (?)) of Stannius.

the superficial ophthalmic, but this is bridged over by a thin membrane of nervous tissue. The superficial ophthalmic now enters the cartilage of the cranium, and immediately expands into a large ganglion. Whilst still in the cranium two nerves are given off, supplying the first 3 sense organs of the supra-orbital canal. Having emerged into the orbit, the superficial ophthalmic courses over the eye muscles, and sometimes, as shown in fig. 1, imperfectly separates into two large bundles, but there is always a bridge of nervous matter connecting them. Owing to the pressure of the eye, the superficial ophthalmic is considerably flattened out in the orbit, and whilst there gives off five nerves, supplying the next 8 sense organs of the supra-orbital canal. The succeeding two organs are supplied by the profundus. The ophthalmic now enters a somewhat long canal opening anteriorly into the orbit, and whilst in it receives and fuses with the ophthalmicus profundus of the Vth. Immediately on leaving this canal the superficialis breaks up and plunges into the huge superficial ophthalmic group of ampullae. The snout of *Chimæra* is divided into three longitudinal compartments by means of two vertical fenestrated ligamentous partitions. These partitions join at right angles anteriorly, and then lie at an appreciable distance beneath and parallel to the skin, the nerves to the sensory canals passing through the fenestræ. The median and largest compartment is occupied by the two superficial ophthalmic groups of ampullæ (see fig. 1), whilst the outer compartments lodge the two buccal groups. The compound nature of the ampullæ of these groups has been accurately figured and described by LEYDIG (7). Each superficial ophthalmic group consists of a small dorsal and a much larger ventral portion (see fig. 1). On entering the snout, the superficial ophthalmic, as above described, breaks up into numerous bundles. Most of these go to ampullae, but six fine bundles separate out, and passing *between* the two ophthalmic groups of ampullæ, supply the remaining 14 sense organs of the supra-orbital canal. The single median sense organ of the snout was supplied from the left side. Excluding the two profundus organs, there were thus 25 sense organs in the supra-orbital canal of the *Chimæra* I dissected.

(2) *Buccal.*—Arises by a single root from the dorsal surface of the brain, on a level with and immediately behind the dorsal border of the restiform body. It then courses downwards and forwards, applied to the surface of the brain, and passes under the ventral root of the superficial ophthalmic, overlying however the roots of the trigeminus. Just opposite the ventral border of the restiform bodies it gives off the dorsal root of the superficial ophthalmic, and before entering the cranium does the same to the hyomandibular trunk. Unless ventral fibres enter into the composition of the buccal by means of these two anastomoses, the buccal consists of dorsal fibres only. Whilst in the cranium the buccal overlies and obscures the root of the trigeminus, but remains quite separate from it, and expands to form the large buccal ganglion. On entering the orbit, the buccal is seen to lie partly over and partly behind the trigeminus (see figs. 1 and 3), and almost immediately gives off from its ventral border the ramus oticus, which

supplies the first 8 sense organs of the infra-orbital line, and also the most ventral of the ampullæ opening on to the surface by the large occipital pores (see fig. 1). The remainder of these ampullæ are, I believe, innervated from the superficial ophthalmic. After entering the orbit the buccal is soon resolved into two large bundles. The ventral bundle ultimately separates out as the inner buccal, whilst the dorsal one, passing under the ventral, becomes the outer buccal. The inner buccal pursues a forward sigmoid course, and gives off 22 branches, supplying the inner buccal group of ampullæ and the 26 sense organs of the dorsal division of the infra-orbital line. The outer buccal divides into two branches. The posterior, after giving off anastomotic twigs to the maxillary, divides into seven bundles supplying the first 8 sense organs of the ventral division of the infra-orbital line. The anterior branch, after sending a twig to the inner buccal group of ampullæ, divides into 7 bundles supplying the outer buccal group of ampullæ and the remaining 6 organs of the infra-orbital line. The outer buccal group of ampullæ curiously differs from the inner buccal and superficial ophthalmic groups, in that the ampullæ, whilst being of the same compound nature, are only about half the size. They are, however, larger than those in the mandibular groups.

(3) *External Mandibular.*—The origin of this nerve from the hyomandibular trunk has been already described (see p. 651). It is connected with two groups of ampullæ—the mandibular and hyoid groups of EWART, and thus consists of two divisions—an anterior and a posterior. The latter division is in a somewhat curious condition. It has only a very few ampullæ connected with it, and breaks up into a plexus supplying a peculiar gelatinous tissue lying immediately above and slightly behind the muscles supplied by the post-branchial division of the facial. Only very few typical ampullæ were identified in this tissue, which probably, therefore, represents a degenerate group, connected perhaps with the aborted spiracle. The external mandibular (posterius) sends several small twigs to the skin, and anastomoses with the post-branchial division of the VIIth. It must therefore contain fibres from the facial proper. From its posterior surface it gives off six twigs, which supply the 7 sense organs of the posterior division of the hyomandibular canal. The external mandibular (anterius) courses downwards and forwards, and gives off from its anterior edge the four twigs which, with two others given off from the posterior edge of the nerve further down, supply the 11 sense organs of the anterior division of the hyomandibular canal. On arriving at a level dorsal to the angle of the jaw, the ext. mandibular anterius breaks up to supply the mandibular group of ampullæ,* which, though small, is very compact, and lies under the skin behind the lower jaw, almost on the mid-ventral line. These ampullæ are smaller than any of those found in the snout, and have not the compound structure of the latter, being simple and kidney-shaped, with the nerve entering at the hilus. Three facts must be noted:—(*a*) several twigs are given off to the skin; (*b*) there is an anastomosis with the mandibular division of the Vth as described by STANNIUS—both these nerves must be considered to

* First discovered by EWART (58, p. 77).

belong to and come from the facial proper; (*c*) a conspicuous nerve passes through the ampullæ, and, dipping down in the direction of the pharynx and then running backwards, ends in a small but totally distinct and very compact group of ampullæ lying at the angle of the mouth between the lower lip and the mandible (see fig. 1).

It will thus be seen that there are three kinds of ampullæ in *Chimæra*, which are—(1) large compound, as in superficial ophthalmic and inner buccal groups; (2) small compound, as in outer buccal group; (3) simple and kidney-shaped, as in mandibular group. The latter are the smallest of the three.

(4) *Lateralis.*—The lateralis arises somewhat in front of and on a slightly higher level than the roots of the vagus, and partly in front of the roots of the glosso-pharyngeal. The posterior rootlets of the lateralis more or less completely obscure the roots of the vagus, but dissection readily shows that the lateralis is quite independent of the vagus. Whilst still in the cranium, the lateralis gives off a dorsal twig, which, uniting with another given off from the ganglion, forms the large dorsal branch to the occipital portion of the lateralis canal. The origin of this nerve is somewhat deceptive, since it seems to arise partly from the 2nd and 3rd branchial ganglia, and requires careful dissection.* The dorsal branch courses straight upwards and gives off eight twigs, which supply the first 9 sense organs of the lateralis canal. The median dorsal portion, or 'post-aural' of GARMAN, was supplied from the right side. The lateralis runs sharply backwards, and, after passing through the vagus foramen, immediately expands into the large lateralis ganglion. The nerve then courses backwards, roughly parallel to the lateralis canal, and innervating it for the whole of its length.

(5) *Auditory Nerve.*—It has long been known that the auditory nerve can no longer be considered an eighth cranial nerve, and it also seems to be generally admitted that the auditory organ is an extremely modified portion of the lateral line system.† I therefore venture to describe it here. The auditory nerve arises by a stout root from the lateral lobes of the medulla in the triangular space inclosed by the ventral root of the superficial ophthalmic and the root of the buccal. It very soon expands into the large auditory ganglion, and gives off a longish nerve to the posterior ampulla. The latter, just at its origin, gives off a very short thick nerve to the sacculus, which contains an hitherto undescribed curiously shaped *hard* otolith (see figs. 4 and 5). Further on, the thickest of the divisions of the auditory nerve arises, which soon divides into a stout nerve to the external ampulla, and another thinner one to the anterior ampulla. The auditory nerve of *Chimæra* thus apparently corresponds to that of *Læmargus*.

Literature.—STANNIUS makes very few references to the facial of *Chimæra* in his text. He figures my post-branchial C, or the major part of what he calls the 'ramus opercularis,' and describes it (p. 61) as supplying the constrictor of the 'Kiemenhöhle.' He seems

* Further complications are the dorsal branches of the cranial spinals (see fig. 2).

† Cp. particularly AYERS (*Jour. Morph.*, vol. vi., 1892) and STRONG (68).

to have devoted most attention to the hyomandibular, which he considered the whole of the VIIth, and which he describes in the following passage (p. 65) :—" Was Chimæra anbetrifft, so gelangt der mit dem grössten Theile des N. trigeminus ausgetretene N facialis cum palatino auf den Boden der Augenhöhle und spaltet sich in drei Zweige. Von diesten tritt der R. palatinus am meisten vorwärts aus. Die anderen beiden Aeste sind der R. hyoïdeus und R. mandibularis. Jeder tritt durch eine besondere Oeffnung des Augenbodenknorpels. Der R. hyoïdeus erstreckt sich über den Unterkiefer, verbindet sich mit einem Zweige des R. mandibularis, gelangt zwischen Unterkiefer und Zungenbein und vertheilt sich hier an häutigen Gebilden und an der Zunge.—Der Ramus mandibularis sendet nach seinem Durchtritt zahlreiche Zweige an die unter dem Augenbodenknorpel liegenden Muskeln und namentlich in die Constrictoren der Kiemenhöhle. Ein vorderer Zweig, der eigentliche R. mandibularis, geht quer weg über den Unterkiefer und den unteren unpaaren Lippenknorpel, verbindet sich mit Zweigen von Unterkieferäste des N. trigeminus und vertheilt sich an der Unterlippe und an der Haut und den Muskeln der Lippenknorpel." It will be seen from the above quotation that STANNIUS' description hardly agrees with mine. He is somewhat ambiguous in his description of the 'R. mandibularis' of the facial. From its origin, one would imagine that he was describing the chorda tympani, but its distribution makes it certain that the 'R. mandibularis' of *Chimæra* is the external mandibular. His omission to figure the chorda confirms this conclusion. STANNIUS figures the buccal nerve somewhat fully, but only barely mentions it in the text (pp. 43–4). He shows more or less completely both inner and outer buccal nerves with their ampullary branches, and also figures a large ventral branch (unlettered) from the buccal trunk, which, unless it be the outer division of the outer buccal, I do not exactly understand. He refers to the orbital sensory canal twigs from the superficial ophthalmic as 'frontal' branches, and points out that there is in *Chimæra* no recurrent branch of the facial as found in Teleostean fishes.

HOMOLOGY OF THE CHORDA TYMPANI.

The question of the homologue of the chorda tympani in fishes is a difficult one to decide, but I think that BALFOUR'S original suggestion* that the præ-branchial division of fishes represents the chorda of mammals has the support of most of the facts. STANNIUS, who was the first to prove that the VIIth was a branchial nerve associated with the spiracle, classified the facial as follows, the hyomandibular trunk giving off—

(1) Palatine *with præ-spiracular or præ-branchial branches to spiracle.*

(2) Hyoidean or Post-Branchial = { (*a*) External mandibular to lateral line. (*b*) Internal mandibular or motor portion. *Continued ventrally on to pharynx.*

Which of these branches STANNIUS homologised as the chorda tympani is not quite clear (see pp. 68–9), but it is certain that the 'internal mandibular' is clearly dis-

* *Comp. Emb.*, vol. ii. p. 378.

tinguished from the præ-spiracular, the former being equivalent to the post-branchial division of the VIIth. JACKSON and CLARKE (16) describe præ-spiracular nerves from the palatine, and a post-branchial internal mandibular *or chorda tympani*. FRORIEP'S mistake (40) has been pointed out too often to be specially mentioned here, but I agree with STRONG that FRORIEP possibly had the right nerve, but gave it the wrong name (*i.e.*, called the mand. int. the mand. ext.). FRORIEP further criticises BALFOUR'S view above. EWART (57) describes the 'palato-facial' or facial proper as follows (I venture to reproduce his description, on account of its having been published in a somewhat inaccessible form):—"The palato-facial arises immediately in front of the auditory by a single root, and as it proceeds outwards it receives a small bundle of fibres from the auditory (the pars intermedia). Having escaped from the cranial wall it expands and divides into the palatine and facial trunks. The facial trunk, which contains numerous ganglionic cells, on leaving the palatine sends several small branches in front of the spiracle (pre-spiracular branches) and a branch which passes backwards external to the auditory capsule. This branch supplies the muscle lying between the auditory capsule and the hyomandibular cartilage, and extends as far as the anterior wall of the hyoid gill. It probably represents the posterior auricular branch of the facial of mammals. The main trunk of the facial proceeds outwards in intimate relation with the hyomandibular nerve to near the outer end of the hyomandibular cartilage. The several bundles of the facial then bend sharply round the hyomandibular cartilage, and come into close contact with the anterior wall of the hyoid gill. Some of the fibres are distributed to the hyoid gill, and others reach and end in the jaw muscles, whilst the remainder proceed to the mucous membrane lying in the hyoid region, *i.e.*, to the part of the floor of the mouth lying between the mandible and the hyoid, or, in the absence of the hyoid, the first branchial arch. These last-mentioned fibres I look upon as representing the chorda tympani of the mammal." It is evident that EWART'S chorda tympani = the mandibularis internus of STANNIUS and JACKSON and CLARKE. STRONG (61 and 68) also homologises the chorda tympani with *a* mandibularis internus, but further confuses matters by identifying what is clearly the præ-spiracular nerve as the internal mandibular. My reasons for this assertion are two: (1) his mand. int. arises *from the base of the palatine*, which is almost invariably the origin of the præ-spiracular nerve;* (2) it consists entirely (?) of splanchnic sensory fibres (and thus agrees with the palatine), whereas the post-branchial division of the VIIth is practically motor. STRONG was apparently misled by the fact that the præ-spiracular of his amphibia (Frog and *Amblystoma*), after its origin from the palatine, accompanied the post-branchial division of the VIIth. I therefore agree with STRONG'S homology, but would substitute the word 'præ-spiracular' for 'internal mandibular.' GAUPP (SCHWALBE'S *Morph. Arb.*, Bd. ii.) and POLLARD (*Zool. Jahr.*, Bd. v.) also considered that the chorda of mammals was

* This assertion, minus the 'almost,' is made upon the reliable authority of STANNIUS. The præ-spiracular is wrongly figured by MARSHALL and HURST, but rightly by STANNIUS for *Acanthias* (Plate II. fig. 1). Cp. further the description of the IXth of *Mustelus* given by RAMSAY WRIGHT (34).

represented by the internal mandibular or post-branchial (facial) of fishes. PINKUS (67) follows STANNIUS in not distinguishing a præ-spiracular nerve, but describes it as a branch of the palatine. He refers to two palatines—a superior and an inferior. The latter arises from the base of the superior, and corresponds to the præ-spiracular division of the VIIth, or the chorda tympani of mammals. The latter homology is recognised by PINKUS; and as he also identifies correctly the mandibularis internus (which is a motor nerve in *Protopterus* as in *Chimæra*), he must be considered the first author to (unwittingly) confirm the view held by BALFOUR.

The above quotations show, I think, that two nerves have been described under the name of 'mandibularis internus.' In fishes the post-branchial division of the facial has been uniformly described as the internal mandibular (cp. STANNIUS, JACKSON and CLARKE, and PINKUS), but in Amphibia the nerve corresponding to the præ-branchial of fishes is wrongly referred to as the internal mandibular (cp. STRONG). The facial proper of fishes, therefore, just over the hyomandibular cleft, divides into 3 nerves, which are: (1) palatine or visceral; (2) præ-branchial or præ-spiracular, arising from the base of (1); (3) post-branchial or post-spiracular, *or internal mandibular*. Both (2) and (3), may, as first pointed out by STANNIUS, be continued ventrally on to the pharynx. This fact, it seems to me, has been too often overlooked in considering the homology of the chorda tympani.

My reasons for regarding the chorda tympani as a præ-branchial nerve are as follows:—

(1) Assuming that there are no visceral clefts between the spiracle and the mouth, and the evidence in favour of these is well known to be far from satisfactory, the branchial divisions of the facial of fishes should be related respectively to the mandibular and hyoid visceral arches. The præ-branchial should course along the posterior edge of the mandible, and may be continued ventrally on to the pharynx *in the immediate vicinity of the mandibular arch.* The post-branchial, on the other hand, should course along the anterior edge of the hyoid arch and supply its muscles, and may also be continued on to the pharynx *between the hyoid and mandibular arches.* These facts were first pointed out by STANNIUS. Further, the præ-branchial should be essentially a splanchnic sensory nerve, and the post-branchial a splanchnic motor nerve.

(2) In fishes having a spiracle, the præ-spiracular nerve arises from the base of the palatine.

(3) It is obvious from (1) and (2) that the nerve I have described in *Chimæra* as the chorda tympani is at least a præ-branchial nerve, and corresponds, for example, to the præ-spiracular of *Læmargus.*

(4) The essential features in the distribution of the chorda in Mammals are: (*a*) it passes (morphologically) under the tympanum; (*b*) anastomoses with the lingual (mandibular) division of the Vth (this is perhaps of not so much importance, as it seems to remain physiologically distinct); (*c*) supplies a gland; (*d*) enters into branchial relations with the mandible; (*e*) supplies the tongue. As I have pointed out, (*b*) is not

of any great importance, (*c*) cannot obtain in Fishes, and (*e*) can only be represented by a ventral continuation on to the pharynx. The chorda tympani is in an exceedingly interesting condition in man,* and seems to exactly correspond to the condition described in Amphibia by STRONG. The great superficial petrosal corresponds, as first shown by STANNIUS, and confirmed by GEGENBAUR and EWART, to the palatine of fishes; and according to many observers the chorda tympani of man *derives a great part at least of its fibres from the base of the great superficial petrosal*, and thus, as in Amphibia, *only accompanies the post-branchial division of the facial* (main trunk of the facial of man). No one who has examined Professor THANE'S diagram of the facial in QUAIN'S *Anatomy* can fail to notice the fundamental resemblance between it and that of larval Amphibians and Fishes (cp. particularly STRONG, p. 186). I therefore suggest that the facial of man divides, as in Fishes, into the following 3 fundamental branches: (1) great superficial petrosal (=palatine or visceral); (2) chorda tympani (=præ-spiracular, arises from base of 1); (3) main trunk (=post-branchial). From the fact that the chorda tympani of Mammals passes morphologically under the tympanum, and as the spiracle of fishes is considered by some to be equivalent to the tympanum + Eustachian tube of Mammals, it has been argued that any representative of the chorda in fishes should have similar relations to the spiracular cleft. This, however, is assuming (1) that the spiracle has been correctly homologised in Mammals (which is still a somewhat open question); and (2) that, on the conversion of the spiracle, the præ-branchial nerve did not do what we know it has done in Amphibia, *i.e.*, accompany the post-branchial, and thus become a topographical but not a morphological post-branchial nerve. We are now, after a consideration of the chorda in Mammals, in a position to define the characteristics of its representative in Fishes. These are: (1) it should arise from the base of the palatine, *i.e.*, the facial should give off its 3 fundamental branches at the same place, and that place above the hyomandibular cleft; (2) should enter into branchial relations with the mandibular arch, and consist essentially of splanchnic sensory fibres; and (3) should have the representative of a lingual branch, *i.e.*, should be continued ventrally on to the pharynx in the region of the tongue. It is obvious that the nerve I have described in *Chimæra* supplies all these conditions; and as we have previously seen that it represents the præ-spiracular nerve of other fishes, we may conclude that this latter nerve is the representative of the chorda tympani of Mammals.

(5) In all the cartilaginous fishes that I have examined the præ- and post-branchial divisions of the IXth and Xth have been united by a stout commissure. I have already described a similar commissure between the chorda and post-branchial divisions of the facial of *Chimæra*.

(6) MARSHALL, in describing the development of the chick,† says that the facial arises as a "large hyoidean or post-branchial branch, *which runs along the hyoid arch*, and a smaller mandibular or præ-branchial branch, which runs forwards over the

* Despite certain assertions to the contrary, the chorda tympani of Mammals must be regarded as distinctively a branch of the VIIth (cp. DIXON, *infra*).

† *Vert. Emb.*, p. 266.

dorsal end of the hyomandibular cleft, and then downwards *a short distance along the mandibular arch*" (italics mine). There is here very little evidence in favour of præ-spiracular gill clefts. Again, in the mammalian facial, the post-spiracular, as usual, is developed first; whilst, later on, the præ-spiracular is given off from the oral side of the facial ganglion in front of the hyomandibular cleft, extends downwards, and *enters into branchial relations with the mandibular arch.* These facts show that it is the præ-spiracular, and not the post-spiracular, the peripheral distribution of which corresponds to that of the chorda tympani. Unfortunately, the early development of the latter is, I believe, not known in Mammals; but, according to my view, it should be formed from the præ-spiracular nerve of the embryo.

I have thus endeavoured to show that whilst the chorda tympani was correctly homologised by STRONG and PINKUS, yet both these observers failed to recognise in it the præ-spiracular nerve of cartilaginous fishes; and further, that the internal mandibular nerve of STRONG is not the internal mandibular hitherto described in Selachians. The latter is simply the ventral continuation on to the pharynx (= mostly splanchnic motor fibres) of the post-branchial division of the facial, and, as such, does not fulfil the requirements of any definition of a homologue of the chorda tympani. In no Selachian is the internal mandibular known to consist of splanchnic sensory fibres, nor does it ever enter into branchial relations with the mandibular arch (cp. quotation from EWART above). STRONG bases his homology of the chorda in Amphibia on three facts, which he says are common both to amphibia and man :—

(1) Both have the same internal origin, *i.e.*, from the 'fasciculus communis.' This is "essentially the central origin of the branchial [visceral sensory (and motor ?)] nerve supply."
(2) Both have the same kind of fibres.
(3) Both have the *same course* and final termination. With regard to the lingual branches, STRONG discovered that the chorda of larval amphibia innervated the pharynx "in the same transverse plane as the location of the future tongue" (cp. *Chimæra*). He also examined adult forms, and found that on the development of the tongue the chorda tympani *passed on to and partly supplied it.*

RAMSAY WRIGHT (34) controverts VAN WIJHE'S statement that the ramus oticus of Ganoids is a branch of the Vth, and his proof that it is a facial branch in *Lepidosteus* and *Amia* brings the Ganoids into my scheme of the lateral line system. He further shows that the spiracular demi-branch or opercular gill of *Lepidosteus* is innervated both by the VIIth and IXth cranial nerves, and hence = the spiracular demi-branch + the hyoidean demi-branch of other fishes. The portion innervated by the IXth is not respiratory, and therefore forms the pseudobranch, whilst the hyomandibular cleft *has no external opening.* It is with regret that one adds that this arrangement cannot be said to hold good for *Chimæra.*

Recent researches on the facial nerve of Fishes and Amphibia enable us to draw up a scheme as to the composition of a typical hyomandibular trunk. It should have the following branches:—

(1) 'Dorsal' branches. Generally absent, but described for *Echinorhinus* by JACKSON and CLARKE.
(2) A visceral sensory (and motor ?) division (palatine and chorda tympani). Includes præ-branchial.
(3) A visceral motor (+ visceral sensory ?) division = post-branchial. (3) and (5) should have a similar proximal course, but be quite separable, as described in *Auchenaspis* by POLLARD (60).

} = Facial proper.

(4) A cutaneous sensory division = anastomosis between IXth and VIIth (JACOBSON'S anastomosis), as described by GORONOWITSCH (45), PINKUS (67), and STRONG (68).*
(5) A lateral line division = external mandibular.

Chimæra is lacking in (1) and (4).

Unless the ganglion cells at the base of the palatine represent the ganglion of the facial proper, I have failed to demonstrate the geniculate ganglion in *Chimæra*. EWART, assenting to the homology between the palatine of fishes and the great superficial petrosal of man, first established by STANNIUS (p. 71), regards these cells as representing the spheno-palatine ganglion of man (57), but does not sufficiently distinguish between his geniculate and spheno-palatine ganglia. I am therefore disposed to agree with STRONG that there is only one ganglion on the facial proper, and that is the geniculate ganglion situated at the base of the palatine, *i.e.*, *where the facial proper divides into its three characteristic branches.*†

Before proceeding to discuss the literature of the lateral line system, I shall briefly refer to the still somewhat vexed question of the roots of the Vth and VIIth. The doubtful points were to a great extent elucidated by the work of MARSHALL and SPENCER on *Scyllium* (28), and the following scheme is based partly upon the results which they obtained, and partly upon recent literature and my own observations. It represents the roots of the Vth and VIIth in a typical fish.

Trigeminus.

(1) Anterior ventral ganglionated. May have two or more rootlets. = ventral tertiary roots of embryo and root of profundus. Mainly sensory (but described as motor by STANNIUS), and partly motor in Cyclostomes.

(2) Posterior ventral ganglionated. = ventral secondary root of embryo. In adult becomes related to VIIth. Largely motor, but also sensory.

* There is no doubt that this nerve is a branch of the IXth, and only accompanies the VIIth.

† Cp. particularly in this connection DIXON'S memoir, *infra*, who seems to me to prove this point. From what this author says on pp. 56 and 65, EWART'S palatine cells cannot correspond to MECKEL'S ganglion.

Facial.

(3) Dorsal from lobus 'trigeminus.' Primary dorsal root of embryo. = *the* lateral line root, and is more or less connected with *all* the lateral line roots. Before MARSHALL and SPENCER'S paper, always described as belonging to the Vth.

(4) Ventral. Secondary ventral root of embryo. In adult closely related to (2). = facial proper root + the accompanying external mandibular. The latter, however, usually leaves it and arises from (3).

(5) Ventral. Development unknown. Always connected with (3). = remainder of lateral line system not included in (3) and (4) (this may be a portion of either the superficial ophthalmic or buccal). Found in *Chimæra*, *Acipenser*, and *Læmargus*. May be in front of (4), but is not so in *Chimæra*. Has been described as belonging to Vth. Seems to be very often missing; and when so, it is probably fused with (4), and hence becomes related to (2).

I have added root (5) principally because it is a very prominent root in *Chimæra*, which, as far as I am aware, is the only fish in which the roots of the Vth and VIIth remain perfectly distinct, and which, therefore, probably shows us the nerves in a primitive condition. The nearest approach to *Chimæra* in this respect are the Pleuronectidæ, as first pointed out by STANNIUS. It is interesting to note that in Amphibia the Vth arises by a single root, and only contains a few motor fibres (STRONG).

With regard to the unity of the lateral line system, which I have maintained above, there is a considerable wealth of evidence showing that at least the superficial ophthalmic and buccal cannot be divided into two nerves. VAN WIJHE (31, p. 27) first showed that these nerves arose by the splitting of a single trunk, and this observation was confirmed by BEARD (35), who further stated that the supra- and infra-orbital canals *arose by the splitting of a single "branchial sense organ."* EWART (58, pp. 66 and 77) favours the view that the superficial ophthalmic and buccal represent a single dichotomised trunk, whilst POLLARD (60)* showed that this was actually the *adult* condition in *Clarias* and *Auchenaspis*. PINKUS (67) proved the same for *Protopterus*, and added the important observation that the common trunk *communicated with the lateralis nerve.* Finally, STRONG (68) established the fact that the lateral line nerves of Amphibia arose by two roots, which had a common internal origin in the brain.

I have previously referred to a nerve known as the 'recurrent facial.' It was first discovered by STANNIUS in *Silurus*, but does not, as stated by him, occur in *Chimæra*. POLLARD figures and describes it in many species of Siluroids (60). It arises from the VIIth portion of the fused Vth and VIIth ganglia, frequently anastomoses with a branch of the lateralis, and in *Clarias* supplies the sensory canal "at the base of the dorsal fin." POLLARD'S description of this important nerve is not as full and as clear as one could wish, but it certainly has no representative either in cartilaginous fishes or in

* This author makes the interesting statement that in *Trichomycterus* there are only two sense organs on the infra-orbital canal, and hence the buccal nerve *is much reduced, and represented only by two twigs.*

Amphibia. Since *Clarias* represents "a very ancient type of the lateral line system," it may be that it is the primitive root of the lateralis, *i.e.*, when this nerve arose from a common lateral line trunk; but further investigations as to its development and adult anatomy are much needed.

It is very strange that none of the three authors who have paid special attention to the ear of *Chimæra* should have observed the very interesting fact that the sacculus contains a *hard* calcareous otolith. I have seen it in three specimens, and both surfaces of it are shown in figs. 4 and 5. BRESCHET (1) says that "il (*i.e.* the sacculus) contient aussi de cette matière amylacée, que nous avons nommé *otoconie*, et une liqueur blanche," and this is his only reference to the otolith. LEYDIG (7) figured and described several otoliths in *Chimæra*, which were soft, round, calcareous bodies, formed of concentric laminæ, and somewhat resembling starch granules. Finally, RETZIUS (29) figures and describes exactly the same bodies as LEYDIG. As it is hardly probable that LEYDIG and RETZIUS should both have made the same mistake, it seems to me desirable that the otolith should be investigated in both genera of Chimæroid fishes. At present *Chimæra* must be regarded as the only cartilaginous fish having a hard otolith.

J. THE GLOSSO-PHARYNGEAL, OR NINTH CRANIAL NERVE (fig. 2).

Before proceeding to the IXth and Xth cranial nerves, it is necessary that I should briefly describe the arrangement of the gills. There is a hyoid and five branchial arches in *Chimæra*. These are so situated in the empty pharynx that the edges bearing the gills point obliquely backwards. These edges are therefore the posterior edges. There is one gill to each arch, consisting, as usual, of two demi-branchs. The hyoidean or opercular gill and the gill on the fourth branchial arch, however, consist of a single demi-branch each. The last or fifth branchial arch, of which only the basi- and cerato-branchial elements remain separate, has no gill whatever, and I did not succeed in tracing any branch of the vagus to it. This must, however, exist. The breathing apparatus of *Chimæra* therefore consists of eight demi-branchs, arranged so as to form five gills, innervated by four nerves—the glosso-pharyngeal and three branchial divisions of the vagus.

The ninth nerve of *Chimæra* arises from the medulla by one large root and two small rootlets below and under cover of the anterior rootlets of the lateralis, as in all cartilaginous fishes (see fig. 2). It passes through the cranium by a separate foramen, and immediately expands into an obvious ganglion. From this ganglion the very fine dorsal branch arises (IX 1), which does not, however, innervate any sense organs of the lateral line, but passes straight upwards to the skin of the occipital region. The glosso-pharyngeal then passes on, and divides into the following branches :—

(1) *Præ-branchial* (IX 2).—Courses at the base of the first or hyoidean or opercular demi-branch. After reaching the base of the hyoid arch, it becomes at first thin and

then very fine, and eventually passes on to the pharynx, terminating, after a long course, a little behind the lower jaw in the mid-ventral line. During its course round the arch it gives off two conspicuous nerves (IX 3) to the first demi-branch.

(2) *Post-branchial* (IX 4).—Runs at the base of the second demi-branch for the greater part of its course. On approaching the base of the first branchial arch, it runs along its outer edge, and then turning sharply inwards and coursing along the inner edge it reaches the pharynx. There it divides into anterior and posterior branches. The posterior branch is short. The longer anterior branch runs obliquely forwards and was lost at about the mid-ventral line, about an inch behind the lower jaw. The post-branchial is a conspicuous nerve, but has no obvious branches.

(3) *Accessory skeletal branch* (*a*) (IX 5).—Under this name I propose to describe those branches of the glosso-pharyngeal and vagus supplying the visceral arches themselves, and which are quite distinct from the præ- and post-branchial nerves. These nerves, which I have found in all the cartilaginous fishes I have hitherto examined, and which appear to have been previously overlooked, may arise from either the præ- or post-branchial nerves, or may have quite a separate and distinct origin. They are always closely applied to the arches they supply, and frequently pierce the substance of the cartilage. In *Chimæra* they may arise at the same level as the præ- and post-branchial nerves. The branch lettered IX 5 courses along the anterior edge of the first branchial arch without giving off any conspicuous twigs, and ends at about the ventral limit of the gill, breaking up into numerous fine branches. It was not traced on to the pharynx.

(4) *Accessory skeletal branch* (*b*) (XI 6).—Courses along the posterior edge of the first branchial arch, running parallel and being an accessory branch to XI 5. No big twigs are given off, and it was not traced on to the pharynx. The branch lettered IX 7 was distributed to the second demi-branch.

(5) *Motor branch* (IX 8).—The independent origin of this nerve has induced me to describe it separately. It courses downwards and forwards, and divides into two. At the point of division it dips down, and then runs sharply forwards *under* the hyoid arch, and adhering to its inner face. Eventually it dips down still more and leaves the arch. The anterior division (IX 9) runs forwards to supply the large levator muscle attached to the anterior face of the hyoid arch. This is the main branch. The posterior division (IX 10) supplies a small muscle attached to the posterior face of the hyoid arch.

(6) *Pharyngeal or visceral branches.*—These nerves are peculiar in *Chimæra*, since one invariably finds at least two to every branchial nerve. One of these nerves, however, is homologous in origin and distribution throughout the series, and will be described as the visceral proper. The other pharyngeal branches will be described as accessory visceral branches. The glosso-pharyngeal has only the latter, of which there are three—all arising from the præ-branchial nerve (IX 11, 12, 13). The most slender of these, however (IX 13), anastomoses with the second (IX 12). There are thus five visceral branches of the glosso-pharyngeal of *Chimæra*—the continuations of the præ- and

post-branchial nerves, representing the efferent and afferent lingual fibres of higher vetebrates, and the three accessory viscerals, representing the single visceral nerve of other fishes.

Literature.—STANNIUS makes a few very brief references to the glosso-pharyngeal of *Chimæra* (pp. 76, 77, and 78), but does not anticipate the above account in any important respect. He further (p. 76) commits the error of stating that the glosso-pharyngeal passes through the same foramen as the vagus, a mistake copied by GEGENBAUR (14), but corrected by HUBRECHT (17). STANNIUS, however, seems to have been the first to describe the dorsal sensory branch of the IXth, which he found in *Spinax* and *Carcharias*, and this discovery has been confirmed by GEGENBAUR (14), and almost every writer on the cranial nerves of fishes since his time. The fact that this branch may innervate a portion of the lateral line system was, I believe, first discovered for *Mustelus* by RAMSAY WRIGHT (34). ALLIS (49) next described a similar case in *Amia*, and further found that the dorsal branch of the IXth in this Ganoid had a separate root and ganglion, and passed through a separate foramen in the skull. POLLARD (60) describes the dorsal branch of the IXth innervating sense organs in the following Siluroids: *Clarias, Trichomycterus, Callicthys*, and *Auchenaspis*. In these fishes the dorsal branch supplied only one sense organ, *which was homologous throughout all the forms* POLLARD *examined*. Finally, EWART and COLE (66) have described the dorsal branch of the IXth innervating three sense organs of the lateral line in *Læmargus*. This variation (?) of the dorsal branch, therefore, must be considered as well established. It is discussed in section C of the present communication.

K. THE VAGUS, OR TENTH CRANIAL NERVE (fig. 2).

If we accept the contention that the vagus is a compound nerve,—and this seems to be the general opinion of zoologists,—the vagus of *Chimæra* must be considered to represent its most primitive known condition. For without any dissection beyond mere exposure, three of the component nerves of the vagus, besides the IXth, may be readily distinguished. These are the first and second branchials and the intestinal, and their ganglia are seen as slight swellings near the origins of the nerves. The third branchial and its ganglion also form a separate nerve, which however, proximally, lies partly under, but quite distinct from, the root and ganglion of the second branchial. All the four nerves pass together with the lateralis nerve, through the same foramen in the skull, and each arises by a separate root from the medulla which may be dissected without much difficulty. The roots are, however, closely opposed, and lie more or less under cover of the root of the lateralis, which also obscures the root of the IXth. The above condition is most nearly approached by the vagus of *Torpedo*, a description of which will be published at some future time. The vagus of *Chimæra*, therefore, must be described as a complex consisting of four perfectly independent nerves. These nerves I propose to describe as Vagi 1, 2, and 3, and the Intestinal.

Vagus 1.

Arises immediately posterior to the large root of the glosso-pharyngeal. On emerging from the vagus foramen it courses slightly forwards, and expands into its ganglion at about the same level as the glosso-pharyngeal. It then runs parallel to the latter for some little distance, but afterwards takes a posterior turn, and passing down a groove bored in the outer face of the first pharyngo-branchial, divides into the following branches (I did not succeed in finding a dorsal branch to vagus 1):—

(1) *Præ-branchial* (X 1^1).—Distributed partly to the third demi-branch. This nerve is undoubtedly homologous to a præ-branchial nerve, although it is distributed rather to the pharynx at the base of the third demi-branch. Dorsally it is in connection with the demi-branch, but ventrally, and especially the small branch X 1^2 and the long anterior branch X 1^3 (from which a slender pharyngeal branch X 1^4 was given off, which was not traced), it undoubtedly innervates the pharynx at the base of the gill.

(2) *Post-branchial* (X 1^5).—Innervates the fourth demi-branch. This nerve somewhat resembles the præ-branchial. It is undoubtedly in connection with its demi-branch dorsally, but ventrally it innervates the pharynx at the base of the gill. Finally, it is continued for a short distance beyond the arch straight on to the pharynx, where it divides into a few branches. This is the largest division of Vagus I, but has no conspicuous branches.

(3) *Extra-branchial nerve* (X 1^6).—This arises, as shown in fig. 2, in a somewhat complicated way from the accessory skeletal branch X 1^8. It is a very fine nerve, and is distributed to the fourth demi-branch.

(4) *Accessory skeletal branch* (*a*) (X 1^7).—Courses along the anterior edge of the second branchial arch. I succeeded in tracing it almost to the base of the arch, but did not find that it had any obvious branches.

(5) *Accessory skeletal branch* (*b*) (X 1^8).—Runs close to the posterior edge of the second branchial arch. It is perceptibly smaller than X 1^7, and was traced to the base of the arch. There were no conspicuous branches.

(6) *Motor-branch* (X 1^9).—This nerve is precisely comparable to the motor branch of the IXth. It arises, however, from the præ-branchial. After running forwards for a short distance it divides into two branches (X 1^{10}, X 1^{11}), both of which pass under the hyoid arch and are distributed to the same muscle supplied by the anterior division of the motor branch of the glosso-pharyngeal (IX 9) accompanying and lying ventral to this latter nerve.

(7) *Visceral proper* (X 1^{13}).—This dips down and passes inwards and backwards under the pharyngo-branchial of the first branchial arch. Whilst under the arch it divides into two branches, of which one (X 1^{14}) continues in the transverse direction, and supplies the levator muscle of the first branchial arch. The other branch (X 1^{15}) takes a forward turn, and is distributed to the pharynx in the vicinity of the same arch.

(8) *Accessory visceral branch* (X 1^{12}).—The accessory visceral in the natural position

lies ventral to the other products of the division of vagus 1, and can only be seen when these have been removed. Like the accessory pharyngeals of the glosso-pharyngeal, this nerve is associated with the præ-branchial. It dips down suddenly and passes straight forwards, first under the first branchial and then the hyoid arches. After coursing forwards and slightly upwards for some little distance, it reaches and ends in the dorsal internal surface of the pharynx, the external surface of the same part of the pharynx being innervated by the accessory visceral branches of the IXth.

Vagus 2.

The second component of the vagus arises from the medulla immediately behind the first. On leaving the vagus foramen it almost immediately expands into a ganglion, which overlaps the ganglion on vagus 3, and passes outwards and slightly backwards. Just distal to the ganglion the slender dorsal branch is given off (X 2^1), which soon bifurcates and is distributed to the skin of the occipital region. Soon after, the motor branch (X 2^7) is given off, and then the nerve passes over the first pharyngo-branchial and lies in a furrow on the second similar to that previously described on the first. The following branches are then given off:—

(1) *Præ-branchial* (X 2^2).—Distributed to fifth demi-branch. It courses at the base of the demi-branch, at some little distance from the arch, as far as the base of the latter. There were no conspicuous branches, and the nerve was not found to be continued on to the pharynx.

(2) *Post-branchial* (X 2^3).—Supplies the sixth demi-branch. It runs somewhat close to the arch at the base of the gill, and having reached the foot of the arch it takes an inward turn and courses along the anterior edge of the arch, and thus reaches the pharynx. There it divides into two, and runs obliquely forwards and inwards, but was not traced far on to the pharynx.

(3) *Accessory skeletal branch* (*a*) (X 2^4).—This arises from the præ-branchial, and is doubtless a skeletal branch, though its distribution is not exactly typical. It is an exceedingly fine nerve, and is associated with the posterior edge of the second branchial arch. I did not, however, succeed in tracing it very far.

(4) *Accessory skeletal branch* (*b*) (X 2^5).—Closely applied to the anterior edge of the third branchial arch. This nerve has no obvious branches, and was not traced to the base of the arch.

(5) *Accessory skeletal branch* (*c*) (X 2^6).—Courses along the posterior edge of the third branchial arch, and is a much finer nerve than X 2^5. There were no conspicuous branches, and I did not succeed in tracing the nerve right round the arch.

(6) *Motor branch* (X 2^7).—Arises from the trunk of vagus 2 as described above, and supplies a longitudinal band-like muscle lying over the gill arches a little to one side of the mid-dorsal line. It is an exceedingly fine nerve, and may easily be overlooked.

(7) *Visceral proper* (X 2^8).—This nerve, like its fellow of vagus 1 (X 1^{13}), arises from

the post-branchial, and has a precisely analogous course. It dips down and passes under the second pharyngo-branchial, and divides into the same two branches. The transverse branch, of course, innervates the levator muscle of the second arch, and not of the first.

(8) *Accessory visceral branch* (*a*) (X 2^{9}).—Slips down through a notch on the outer edge of the first pharyngo-branchial, and courses obliquely forwards and inwards direct on to the pharynx.

(9) *Accessory visceral branch* (*b*) (X 2^{10}).—Springs from the præ-branchial, and runs obliquely downwards and forwards on to the pharynx. It passes under the second branchial arch, and, after dividing into two, ends laterally on the pharynx, somewhat in front of the second branchial arch.

(10) *Accessory visceral branch* (*c*) (X 2^{11}).—This is a very fine nerve, and passes downwards and forwards straight on to the pharynx. It arises from the præ-branchial.

Vagus 3.

Arises immediately behind and in contact with the root of vagus 2. It leaves the vagus foramen in company with the latter, and lies underneath and slightly behind it. The ganglion is obscured by that of vagus 2, but shortly afterwards the nerve takes a backward turn and leaves vagus 2, passing over the first and second pharyngo-branchials. Before it breaks up, it gives off a motor twig (X 3^{4}), and finally passing down a similar groove in the common pharyngo-branchial (P B^{1}) to those described on the first and second visceral arches, divides into the following nerves :—

(1) *Præ-branchial* (X 3^{1}).—Distributed to seventh demi-branch. It runs at the base of the gill to the base of the arch. No conspicuous branches were found, neither was the nerve traced on to the pharynx.

(2) *Post-branchial* (X 3^{2}).—Supplies eighth or last demi-branch. Dorsally and laterally this nerve is in connection with its demi-branch and courses at its base, but ventrally it approaches the arch, and on arriving at its base turns inwards, and passing across the arch is continued on to the pharynx, where it divides into two or three branches. There were no other obvious branches.

(3) *Accessory skeletal branch* (X 3^{3}).—Passes along the posterior edge of the fourth branchial arch, but was not traced right round. It is a very slender nerve, and does not give off any noticeable branches.

(4) *Motor branch* (X 3^{4}).—The origin of this nerve from the main trunk of vagus 3 has been already described. It is a precisely similar nerve to (X 2^{7}) from the preceding component of the vagus, and is distributed to the same muscle.

(5) *Visceral proper* (X 3^{5}).—Dips down and passes under the common pharyngo-branchial (P B^{1}). It then courses obliquely inwards and forwards, and reaches the pharynx. There it divides into two main branches, which form a plexus. The inner or posterior main branch pursues a transverse direction almost on to the mid-dorsal line. This nerve (X 3^{5}) is one of the largest of the visceral branches.

(6) *Accessory visceral branch* (*a*) (X 3^6).—Arises from the præ-branchial, and passes under the third branchial arch downwards and forwards to the pharynx.

(7) *Accessory visceral branch* (*b*) (X 3^7).—Also from præ-branchial. This relatively stout nerve courses downwards and forwards under the third branchial arch, to reach the pharynx in the neighbourhood of the anterior lateral edge of the arch. It might almost be described as an accessory skeletal branch.

(8) *Accessory visceral branch* (*c*) (X 3^8).—Springs from the accessory skeletal branch X 3^3, and dips down in front of the fourth branchial arch. It keeps to the anterior edge of the arch, and is distributed to the pharynx dorsally in that region.

(9) *Accessory visceral branch* (*d*) (X 3^9).—Arises from the post-branchial, and passes forwards over the fourth branchial arch, external to the other nerves. It is a very slender nerve, and innervates the pharynx near the dorsal anterior edge of the arch.

Intestinal Nerve (I.).

This division of the vagus arises as its most posterior root, and soon after leaving the cranium expands into an obvious ganglion. It then passes outwards and backwards, and splits up to form a very complicated plexus on the pharynx and proximal portion of the œsophagus. Several of the bundles unite again to form somewhat large nerves, and these, in their turn, break up into another plexus on the distal portion of the œsophagus and the stomach. The latter plexus was traced as far as the pylorus, *i.e.*, the beginning of the spiral valve. Both plexuses lie on the circular muscles of the œsophagus and stomach, beneath the pigmented serous coat, and are thus easily seen without any dissection. In both the specimens given me by Professor EWART a very slender nerve was, with much difficulty, traced on to the wall of the sinus venosus, but this was the only branch of the vagus I succeeded in tracing to any portion of the heart.

Literature.—To STANNIUS (6) belongs the credit of having first discovered the important fact that the branchial nerves may be continued ventrally on to the pharynx, which continuations, therefore, representing the lingual fibres of the Vth, VIIth, and IXth cranial nerves of higher vertebrates. GEGENBAUR (14), however, as is well known, first established its compound nature in *Hexanchus*, but did not find that each of its components had a separate ganglion.* JACKSON and CLARKE (16) described a common vagus trunk in *Echinorhinus* and a common dorsal branch, but the former statement probably needs revision. EWART (51) repeated this statement for *Læmargus*, except that he found a separate ganglion for vagus 1; but I understand that Professor EWART has since found that the vagus trunk of *Læmargus* and its compound ganglion may with care, be separated into its constituent branchial and intestinal nerves, each with its separate ganglion. The same, therefore, doubtless applies to *Echinorhinus*. In 1889 SHORE and EWART (50 and 51) independently announced that the vagus of the

* The division of the vagus attempted by GEGENBAUR into representatives of the vagus, spinal accessory, and hypoglossus of higher vertebrates cannot any longer be maintained.

Skate could be resolved into six nerves (lateralis, intestinal, and four branchials) with six ganglia, thus very materially adding to the discoveries made by GEGENBAUR in *Hexanchus*. EWART (53) has also made similar statements with regard to *Torpedo*, which I can further supplement with the observation that in this animal each division of the vagus arises by a separate root and rootlets, amongst which there is only a slight intermingling. In *Chimæra*, however, the segmentation of the vagus is seen in its most primitive known condition, for each constituent has an obvious ganglion, and an equally obvious separate origin from the brain. One learns, therefore, with some surprise, that the vagus does not exhibit segmentation in its earliest development, the ganglion of vagus 1 only being separate, the others forming a compound mass.

It seems to the writer that further investigations on the lines followed by SHORE (48 and 50) are much needed. This author describes ganglion cells in connection with the dorsal branch of the vagus of the Skate, which he believes to be the equivalent of a dorsal root ganglion of a spinal nerve. This can hardly be admitted at present, since there is good reason to believe that the ganglion on the dorsal root is in connection with splanchnic afferent fibres, and this connection is not demonstrated by SHORE in the Skate. Further work may nevertheless prove the assumption. Besides discovering the ganglion mentioned above, SHORE found that there were ganglion cells in the præ-branchial branches of the vagus. His main conclusions, derived from a study of the sizes of the nerve fibres, are that the "branchial nerves were formed by the separation of the splanchnic rami of some of the anterior spinal nerves from their corresponding somatic rami in relation to the chordate respiratory system"; and further that "the branchial ganglia [with the intestinal] are comparable to, and are probably morphologically equivalent to, what GASKELL has called the vertebral or lateral set of ganglia of the sympathetic, and the præ-branchial ganglia are the equivalents in every sense to the pre-vertebral or collateral set of ganglia of the so-called sympathetic system." SHORE therefore believes that the vagus of the Skate contains the visceral but not the somatic elements of a spinal nerve, and is a compound, not of several complete segmental nerves, but of the visceral components of the anterior spinal nerves, the corresponding somatic components of which have remained separate. The branchial divisions of the vagus must, hence, be considered secondary developments in connection with the breathing apparatus. It must be obvious to any one who has followed the preceding pages that the bulk of the evidence favours SHORE'S views; but whilst we must, at present at any rate, regard the branchial muscles as belonging to the visceral system, it must not be forgotten, as STRONG points out (p. 197), that there is a distinction between vaso-motor and branchio-motor fibres, and it is also necessary to emphasise STRONG'S warning that too much reliance must not be placed upon the size of nerve fibres. Nevertheless, all studies of adult cranial nerves should, where possible—this, I regret, is not in *Chimæra*—be both anatomical and microscopical, so that results obtained under one section of the work may be checked by those obtained under the other. The sharp distinction drawn by SHORE between præ- and post- branchial nerves undoubtedly obtains,

though possibly not in the sense intended by SHORE; and I have already taken advantage of this distinction when discussing the homology of the chorda tympani.

L. THE ANTERIOR SPINAL NERVES (fig. 2).

Like *Læmargus*, *Hexanchus*, and most Elasmobranchs, the anterior spinal nerves of *Chimæra*, which as usual have no dorsal roots, pass through the cranium. How many, however, is not so easily distinguishable as in other Elasmobranchs; but as numerous rootlets combine to form two main nerves (emerging, however, from the skull by three foramina), at least two may be described. These two spinal nerves unite to form the brachial nerve, and I propose to call them the cranial spinal nerves.

First cranial spinal (I).—Arises by seven rootlets, which unite to form two roots; the anterior root emerges from the medulla under cover of the posterior roots of the vagus, and has four rootlets. The roots of the intestinal division of the vagus seem to anastomose with this root, but really pass underneath it. The posterior root (three rootlets) passes through a separate canal and unites with the anterior root just outside the cranium. At the point of union a single dorsal branch (see *Sp. d*) is sent up to the skin. The two roots having united to form the first cranial spinal, the latter dips down suddenly at right angles towards the ventral surface.

The posterior root of this cranial spinal has a more ventral origin than the anterior, and it may have more than three rootlets.

The first cranial spinal, therefore, has no dorsal root and one dorsal branch.

Second cranial spinal (II).—Arises by six rootlets, which go to form two roots. These two roots remain to some extent distinct, but there is an exchange of fibres immediately outside the cranium. At this point two dorsal branches are given off to the skin, and one of these soon divides into two (see *Sp. d*). This fact does not necessarily indicate that this cranial spinal is a compound of three, since a single spinal nerve of the Skate may have as many as four dorsal branches (see EWART and COLE, 66).

The anterior root of this spinal has at least two rootlets (and may have three), whilst the posterior root has at least four. These two roots, after mingling outside the cranium, continue as two nerves, which dip down sharply at right angles towards the ventral surface. The anterior nerve anastomoses with the main trunk of the first cranial spinal, forming a conspicuous nerve, whilst the posterior joins on to the product of the above fusion some little distance further down, to form the large brachial nerve (*Sp.* III).

The second cranial spinal, therefore, has no dorsal root and three dorsal branches.

The brachial nerve is distributed to the pectoral fin (one branch running in a canal (*Sp. F.*) bored in the pectoral girdle), and I have seen it sending a branch to the muscles of the last or fifth branchial arch. This is the only nerve I have traced to this arch.

My dissections of the remaining spinal nerves are not sufficiently complete to be described here.

Literature.—The cranial spinal nerves were first described by STANNIUS in Ganoids, where there seem to be two. VAN WIJHE confirmed the existence of these nerves in Ganoids, and followed the interpretation of them first adopted by GEGENBAUR. The latter (14) thought they represented the ventral roots of the vagus, and considered the true roots of the vagus to be the dorsal roots. He further compared the two sets of roots to the dorsal and ventral roots of the spinal nerves, and, further, his inferior roots to the hypoglossus of Amniota. JACKSON and CLARKE (16) describe four cranial spinals in *Echinorhinus*, the last three of which unite with the brachial plexus, which itself communicates by an anastomosis with the vagus. They follow the interpretation of these nerves given by GEGENBAUR. EWART (51) pointed out that the so-called inferior roots of the vagus or cranial spinal nerves were simply the most anterior spinal nerves minus their dorsal roots; and the fact that in the Skate these nerves pass, not through the skull, but through the vertebral column, practically establishes EWART's contention (see EWART and COLE, 66). It is difficult to see what doubt there could ever have been about the matter, seeing that the distribution of a cranial spinal is distinctively that of the ventral root of a spinal nerve. That these nerves correspond to the hypoglossus of higher vertebrates seems to be pretty well established, since the latter apparently consists of the ventral roots of one or more spinal nerves. It is therefore interesting to note that, according to DOHRN and other embryologists, the hypoglossus must not be confounded with the vagus.

P.S.—I regret that Dr DIXON's memoir on the Vth nerve of man* only came into my hands after the above was written. I have therefore only been able to make very slight use of it, and must refer readers interested in the subject to the original paper itself. The same applies to Miss PLATT's work on *Necturus*.† Miss PLATT describes four sense organs of the infra-orbital line as being innervated by twigs *composed of buccal and profundus fibres in equal proportions.* She further quotes DOHRN as believing it possible that profundus fibres may accompany the superficial ophthalmic of the facial. This seems to me to be a confirmation of my statement that the profundus fibres of *Chimæra* to the supra-orbital canal are simply accompanying fibres of the superficial ophthalmic of the facial. I think it must now be admitted, and provided for, that the fibres of one cranial nerve may accompany another and perfectly distinct cranial nerve. JACOBSON's anastomosis is an excellent example of this (cp. STRONG and DIXON). Miss PLATT's statements on p. 520 *et seq.*, concerning the anastomosis between the trigeminus and buccal (which she calls the buccalis profundus) are of a very interesting character, but I may express surprise to find her "hesitating" to confirm STRONG's statement that the "trigeminus proper does not participate in the innervation of the lateral line system" (p. 530). I note, further, that Miss PLATT points out STRONG's error *re* the

* "On the Development of the Branches of the Fifth Cranial Nerve in Man," *Trans. Royal Dublin Soc.*, vol. vi. p. 19, 1896.

† "Ontogenetic Differentiations of the Ectoderm in *Necturus*," *Q.J.M.S.*, vol. 38, No. 152, p. 485, 1896.

internal mandibular, which latter nerve she agrees with me in regarding as essentially the post-branchial division of the facial, and STRONG'S nerve is certainly *not* a post-branchial nerve. I have no doubt from Miss PLATT'S description and figure that her 'external palatine' is the homologue of the præ-spiracular of fishes, and therefore of the chorda tympani of mammals.

SUMMARY.

1. The present communication contains practically the first account of the nerves of any Holocephalous fish.

2. Sensory canals in general may be said to consist of four divisions—lateral, supra-orbital, infra-orbital, and hyomandibular (operculo-mandibular). These divisions have been found to be innervated from the VIIth and Xth nerves only in all forms carefully examined, and any exceptions to this rule will probably break down, as many have already broken down, on investigation. Representatives of all the five classes of fishes, and of the Amphibia, have been described as falling in with the above scheme.

3. The lateral line divisions of the VIIth, IXth, and Xth nerves of Fishes and Amphibia must be considered as forming a single and perfectly independent system of nerves, developed in connection with a special sensory system, and associated mostly with the facial nerve. It is therefore erroneous to suppose that the sense organs of the lateral line have any 'segmental' value.

4. Fibres from one cranial nerve may accompany the branches of another.

5. The canals of the lateral line system must be classified according to their innervation, and not according to the relative position they may occupy to other parts of the body.

6. An accurate definition of a 'segmental' nerve is perhaps not at present possible. The cranial nerves may not have any 'segmental' value in the accepted sense of the term.

7. The lateral line system of Fishes and Amphibia is innervated as follows: lateral canal and occipital commissure = lateralis (vagus); supra-orbital canal = superficial ophthalmic (facial); infra-orbital canal = buccal + otic (facial); hyomandibular or operculo-mandibular canal = external mandibular (facial). The association of the lateralis with the vagus must have been secondarily acquired, and doubtless all the lateral line nerves arose primitively by a single root from the 'tuberculum acusticum.'

8. The chorda tympani of Mammals is represented in Fishes and larval Amphibia by the præ-spiracular or præ-branchial division of the facial.

9. The roots of the Vth and VIIth, and the post-spiracular hyomandibular trunk, have in the typical Selachian the composition stated on pp. 662–3.

10. The superficial ophthalmic and buccal divisions at least of the lateral line system must be regarded as having arisen by the splitting of a single trunk, and the supra-orbital and infra-orbital canals must also have arisen by a similar process.

11. The 'recurrent facial' of Teleostean fishes has no homologue in Selachians, and requires further investigation.

The following facts relating specially to *Chimæra* may be noticed:—

12. The eye muscle nerves have the normal distribution.

13. The trigeminus, except the usual anastomosis with the buccal division of the lateral line system, remains perfectly distinct from the VIIth, and the fusion between the roots of these two nerves so characteristic of other Selachians does not obtain.

14. The profundus is a branch of the Vth, and sends twigs to two sense organs of the supra-orbital canal. It afterwards completely fuses with the superficial ophthalmic of the lateral line system.

15. The superficial ophthalmic of the Vth retains its individuality, and does not, in the typical condition, fuse with the nerve of the same name belonging to the lateral line system, nor does it innervate any portion of the latter.

16. A pharyngeal branch arises from the maxillary division of the Vth, and possibly others from the mandibular division. The latter anastomoses with the external mandibular division of the lateral line system.

17. Despite the complete absence (?) of a spiracle, the facial has the structure of a typical branchial nerve.

18. All the lateral line nerves arise by separate roots, the superficial ophthalmic and external mandibular both having dorsal and ventral roots.

19. The sacculus contains a hard, calcareous otolith of curious shape, hitherto undescribed.

20. The glosso-pharyngeal does not innervate any sense organs of the lateral line.

21. The vagus is in a more primitive condition than in any other known vertebrate, consisting of four separate ganglionated nerves, each arising by a separate root from the brain.

22. The first two spinal nerves pass through the cranium, and have no dorsal roots. These must be regarded as portions of spinal nerves, doubtless representing the hypoglossus of higher vertebrates, but not connected with the vagus.

23. On the whole, the cranial nerves of *Chimæra* closely resemble those of *Læmargus*, and in this respect at any rate *Chimæra* is nearly related to the Elasmobranchs.

May 1896.

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EXPLANATION OF PLATES.

Fig. 1. Diagram of the principal nerves of *Chimæra monstrosa*, seen from the left side. The glossopharyngeal and vagus will be found correctly shown in Fig. 2.

B. Buccal trunk and ganglion (lateral line system —for root, see fig. 3).
B^1. Inner buccal nerve.
B^2. „ „ group of ampullae. Note branch from inner buccal nerve supplying it, and also an accessory twig (†) from the outer buccal nerve.
B^3. Outer buccal nerve (note its two divisions).
B^4. Outer buccal group of ampullae (note nerve from outer buccal supplying it).
B^5. Twigs anastomosing with maxillary (? see text, p. 645).
B^6. Twig supplying the most ventral occipital ampulla (remainder innervated from superficial ophthalmic ?).
B^7. Otic branch of buccal.
C. Cerebral hemispheres.
Cb. Cerebellum.
c.g. Ciliary ganglion.
c.n. Ciliary nerves.
C.R. Corpora restiformia.
E. Dotted line indicating border of eye.
e.r. External rectus.
H. Hyomandibular trunk and ganglion (see fig. 3).
H^1. Palatine.
H^2. Chorda tympani.
H^3. External mandibular (anterius—lateral line system).
H^4. Facial proper *a* } = { postbranchial division
H^5. „ „ *b* } = { of facial.
H^6. External mandibular (posterius—lateral line system). Note very small hyoid group of ampullae (dotted line).
H^7. Large mandibular group of ampullae.
H^8. Small mandibular group of ampullae.
H.C. Hyomandibular canal (violet).

I.C. Infra-orbital canal (red).
In. Intestinal (vagus).
in.r. Inferior rectus.
i.o. Inferior oblique.
i.r. Internal rectus.
L. Lateralis (lateral line system).
L.C. Lateral canal (brown).
M. Mouth.
Md. Medulla.
N.S. Nasal sack.
O. Branchial aperture formed by opercular fold.
O.L. Olfactory lobes.
Op. Optic lobes.
P.C. Profundus canal (green).
pt. Pituitary body.
r.b. Radix brevis.
r.l. Radix longa.
S.C. Supra-orbital canal (blue).
Sch. Schwalbe's ciliary ganglion and nerve.
s.o. Superior oblique.
S.O. Superficial ophthalmic (lateral line system). For roots, see fig. 3.
S.O^1. Partial separation of above into two band-like nerves. The dorsal one is thinner and not so broad as the ventral.
S.O^2. Superficial ophthalmic group of ampullæ (composed on each side of a large and a small group). Note distribution of superficial ophthalmic nerve to this group. * Supply small isolated groups of ampullæ.
s.r. Superior rectus.
Th. Thalamencephalon.
V.C. Position of visceral clefts.

I. Olfactory nerves.
II. Optic nerve.
III. Roots of oculo-motor.
III^1. Branch of above to superior rectus.
III^2. Dorsal ramus of oculo-motor to internal rectus.
III^3. Ventral ramus to inferior oblique.
III^4. Branch of above to inferior rectus.
IV. Trochlearis emerging from furrow separating optic lobe and medulla.
IV^1. Distribution of above to superior oblique.
V. Position of roots of trigeminus (see fig. 3).
V^1. Gasserian ganglion.
V^2. Profundus and its ganglion.
V^3. Branch from profundus supplying two sense organs of supra-orbital canal (= profundus canal) and also sending twigs to skin.
V^4. Trunk of trigeminus.
V^5. Maxillary or superior maxillary.
V^6. Mandibular or inferior maxillary.
V^7. Branch really from mandibular to masseter muscle of jaw.
V^8. Anastomoses between buccal and maxillary nerves.
V^9. Superficial ophthalmic of Vth.
V^{10}. Motor (?) branch of profundus.
V^{11}. Visceral branch of Vth.
VI. Abducens.
VI^1. Distribution of above to external rectus.
VIII. Auditory. *a*, to anterior ampulla; *b*, to external ampulla; *c*, to sacculus; *d*, to posterior ampulla.
IX. Glossopharyngeal } diagrammatic.
X. Vagi 1, 2, and 3 }

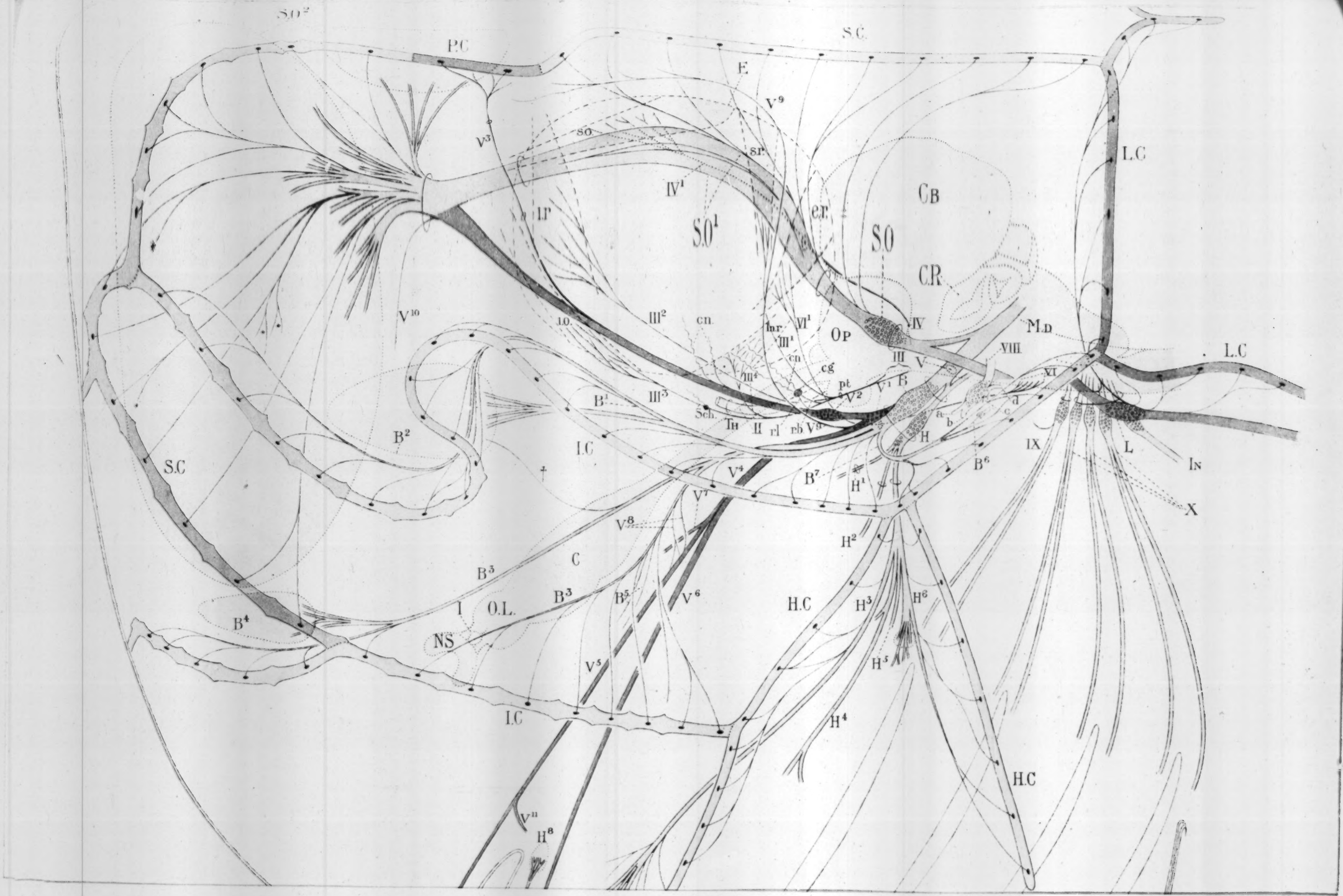
FIG. 2. Semi-diagrammatic figure of glossopharyngeal, vagus, and cranial spinal nerves of *Chimæra monstrosa*, seen from left side. The visceral skeleton was drawn from a preparation in Prof. HOWES' Laboratory, Royal College of Science, South Kensington.

B.B. Basi-branchial.
B.B^1. Basi-branchial of last or fifth visceral arch.
B.H. Basi-hyal.
C.B. Cerato-branchial.
C.H. Cerato-hyal.
Cp. Median ventral copula.
Cp^1. Lateral ventral copulae.
Cp^{11}. Copula between fused fourth and fifth epi-branchials and pectoral girdle.
E.B. Epi-branchial.
E.B^1. Epi-branchial of fused fourth and fifth visceral arches.
H.B. Hypo-branchial.
H.B^1. Hypo-branchial of fourth and fifth visceral arches.
H.M. Hyomandibular.
I. Intestinal (vagus).
L. Root lateralis (lateral line system). Roots of branchial divisions of vagus lie under cover of this root. Note position of vagus foramen.
Md. Medulla.
Mn. Lower jaw.
O. Opercular cartilages supporting opercular fold and hyoidean demibranch.
P.B. Pharyngo-branchial.
P.B^1. Pharyngo-branchial of third and fourth and fifth branchial arches.
P.F. Skeleton of pectoral fin.
P.G. Pectoral girdle.

Sk. Skull.
Sp. Roots of anterior spinal nerves without dorsal roots passing through the cranium. Only one foramen shown.
I. First cranial spinal.
II. Second „ „
Sp.III. Brachial nerve.
Sp.d. Dorsal branches of the cranial spinals.
Sp.F. Foramina by which portion of brachial nerve enters pectoral girdle (on *inner* surface of the pectoral girdle).
IX. Root of glossopharyngeal. Note the two rootlets, its origin from under root of lateralis, and its separate foramen.
IX. 1. Dorsal branch of glossopharyngeal.
„ 2. Prae-branchial.
„ 3. Conspicuous branches of above to first demibranch.
„ 4. Post-branchial.
„ 5. Accessory skeletal branch to anterior edge of first branchial arch.
„ 6. Accessory skeletal branch to posterior edge of first branchial arch.
„ 7. Branch of 6 to second demibranch.
„ 8., „ 9., „ 10. } Motor branches.
„ 11., „ 12., „ 13. } Pharyngeal branches.
X. 1. Root and ganglion of vagus 1.
X. 1^1 Præ-branchial.
„ 2, „ 3, „ 4 } Branches of above to pharynx.
„ 5 Post-branchial.
„ 6 Branch of accessory skeletal $X1^8$ to fourth demibranch.
X. 1^7 Accessory skeletal branch to anterior edge of second branchial arch.
„ 8 Accessory skeletal branch to posterior edge of second branchial arch.
„ 9, „ 10, „ 11 } Motor branches.
„ 12 Accessory visceral branch from præ-branchial.
„ 13 Visceral proper.
„ 14 Branch of above to the levator of first branchial arch.
„ 15 Other branch of above to pharynx.
X. 2 Root and ganglion of vagus 2.
X. 2^1 Dorsal branch.
„ 2 Præ-branchial.
„ 3 Post branchial.
„ 4 Accessory skeletal branch to posterior edge of second branchial arch.
„ 5 Accessory skeletal branch to anterior edge of third branchial arch.
„ 6 Accessory skeletal branch to posterior edge of third branchial arch.
„ 7 Motor branch.
„ 8 Visceral proper.
„ 9, „ 10, „ 11 } Accessory visceral branches.
X. 3. Root and ganglion of vagus 3 (seen to be underlying vagus 2).
X. 3^1 Præ-branchial.
„ 2 Post-branchial.
„ 3 Accessory skeletal branch to posterior edge of fourth branchial arch.
„ 4 Motor branch.
„ 5 Visceral proper.
„ 6, „ 7, „ 8, „ 9 } Accessory visceral branches.

FIG. 3. The roots of the trigeminal and facial nerves of *Chimæra monstrosa*, seen from the left side. *CB.* cerebellum; *C.R.*, corpora restiformia; *MD.*, medulla; *VII.*^{1}, ventral root of superficial ophthalmic (lateral line system); *4*, dorsal root of same; *7*, ganglion of same; *S.O. VII.*, superficial ophthalmic (lateral line system); *VII.*^{2}, root of buccal (lateral line system); *B.*, buccal; *5*, nervous roof of triangular space formed by the ophthalmic and buccal nerves; *8*, ganglion of buccal; *VII.*^{3}, root of hyomandibular trunk (facial and lateral line system); *6*, lateral line (?) dorsal root of same (external mandibular ?); *H.*, hyomandibular trunk; *9*, ganglion of same; *PL.*, palatine; *C.T.*, chorda tympani; *10*, ganglion cells at root of palatine; *V.*, roots (secondary and tertiary) of trigeminus; *TR.*, trigeminus; *2*, ganglion of same (Gasserian); *S.O. V.*, superficial ophthalmic of the Vth; *MX. MN.*, maxillary (superior maxillary) and mandibular (inferior maxillary) divisions of same; *P.*, profundus division of same; *3*, ganglion of latter; *1*, foramen through which Vth and VIIth nerves enter orbit; *VIII.*, root of auditory nerve.

FIGS. 4 and 5. Otolith from sacculus of *Chimæra monstrosa*, drawn from both sides. × 15.


S.O.²
P.C
S.C
E
V⁹
S.O
S.R
V³
IV¹
I.R
S.O¹
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CB
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C.R
L.C
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10
III²
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VI¹
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III
V
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pt
V₁
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V₂
VI
L.C
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III³
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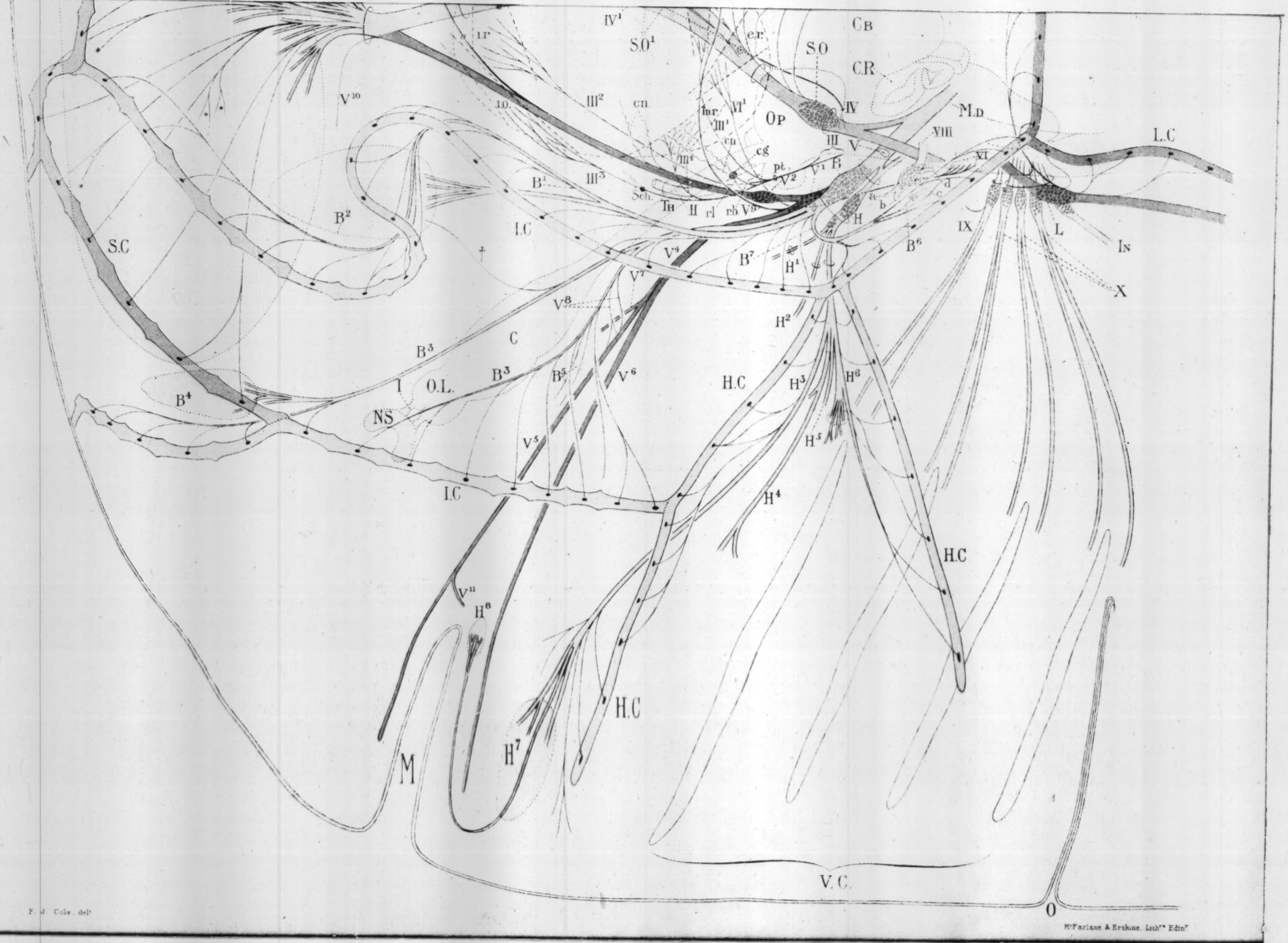
V⁹
a
b
c
d
H
IX
L
IN
B²
I.C
S.C
V⁴
B⁷
H¹
B⁶
X
V⁷
V⁸
H²
C
B⁵
B³
B³
V⁶
H.C
H³
H⁶
I
O.L.
B⁴
NS
V⁵
H⁵
I.C
H⁴
H.C
V¹¹
H⁸


IV¹
S.O¹
e.r.
C.B
S.O
C.R
V¹⁰
10.
III²
cn.
Inr.
VI¹
III¹
Op
IV
M.D
VIII
L.C
cn
III
V
cg
III⁴
pt.
V¹
V²
Fl
XI
B¹
III³
Sch.
TH
II
rl
rb
V³
H
a
b
c
d
IX
L
IN
X
B⁶
B²
I.C
S.C
V⁴
B⁷
H¹
V⁷
V⁸
H²
C
B³
B³
B⁵
V⁶
H.C
H³
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I
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B⁴
NS
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I.C
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H.C
V¹¹
H⁸
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H⁷
V.C.
O
P. J. Cole, del.
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Mr Frank J. Cole on the Cranial Nerves of Chimaera monstrosa.— Plate II.

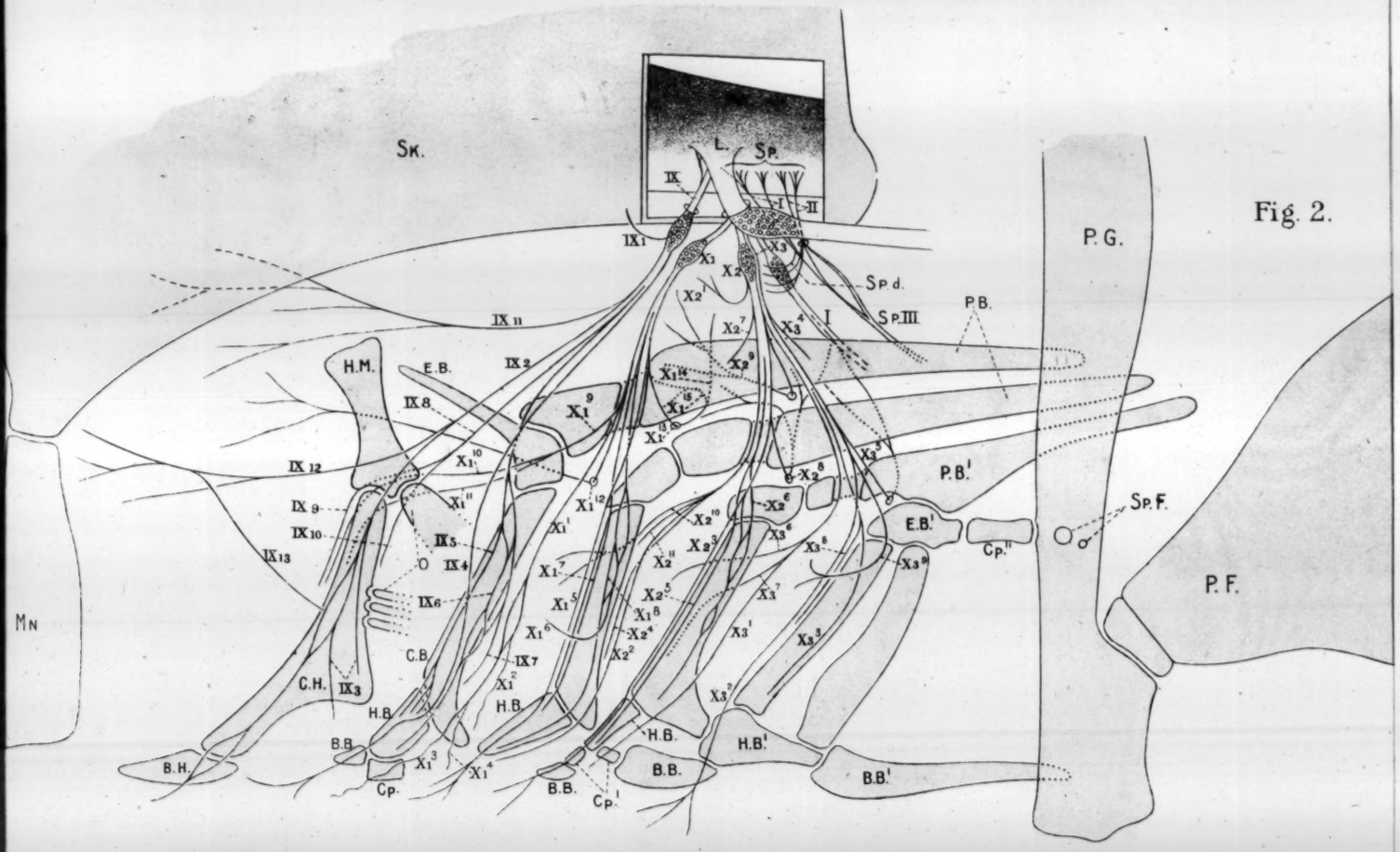


Fig. 2.

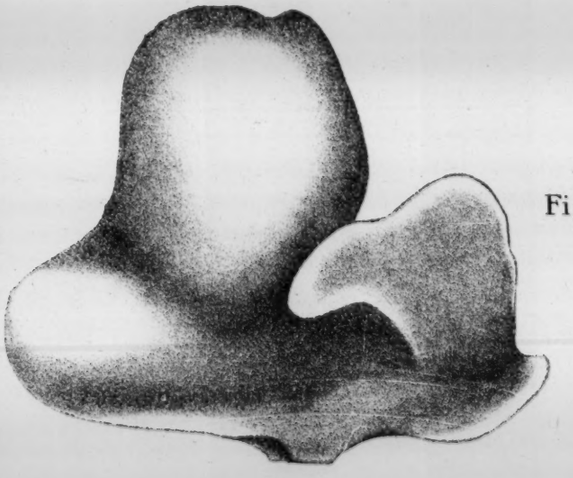


Fig. 4.

Fig. 5.

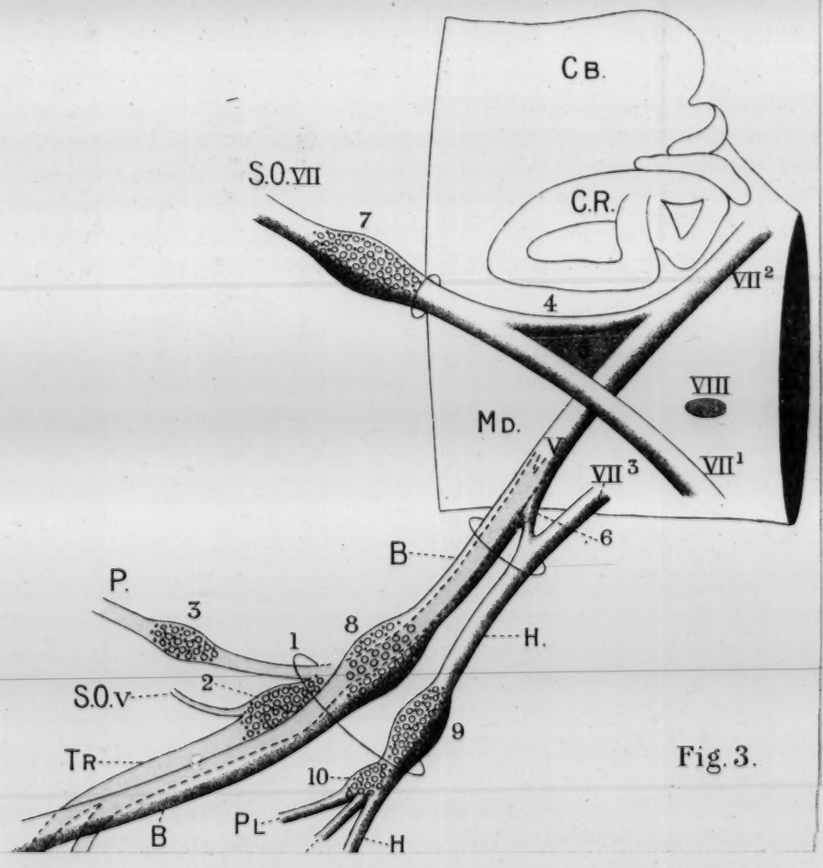


Fig. 3.

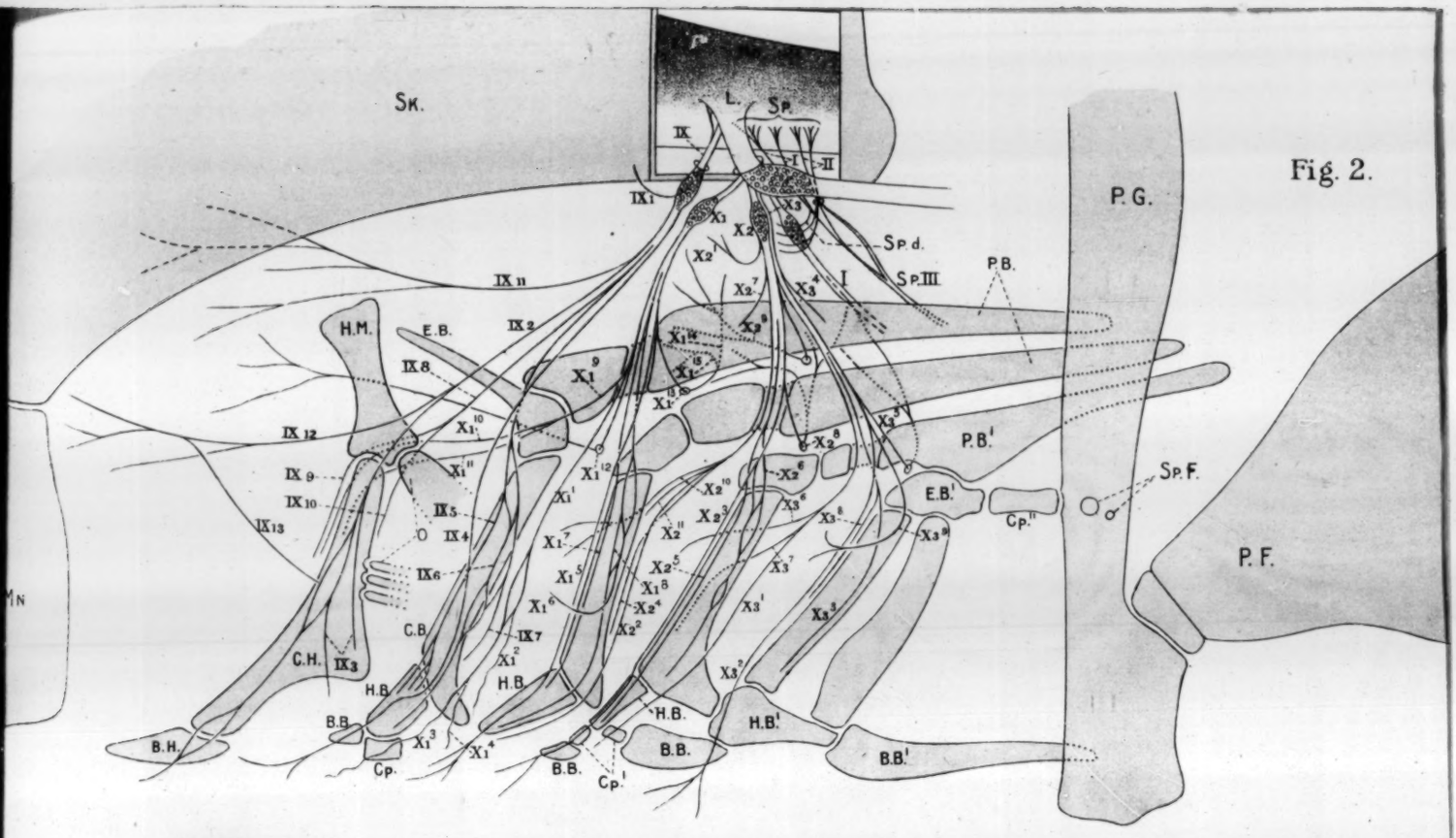


Fig. 2.

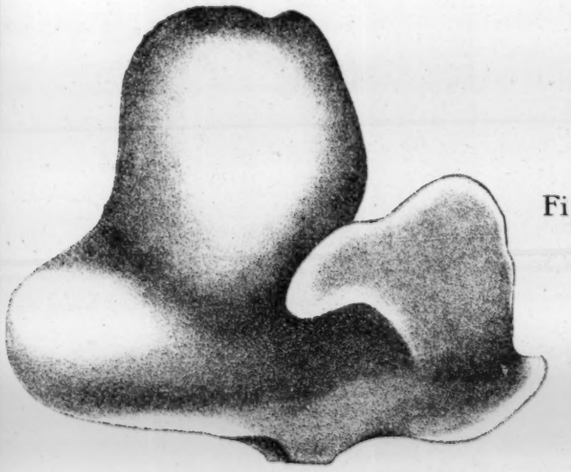


Fig. 4.

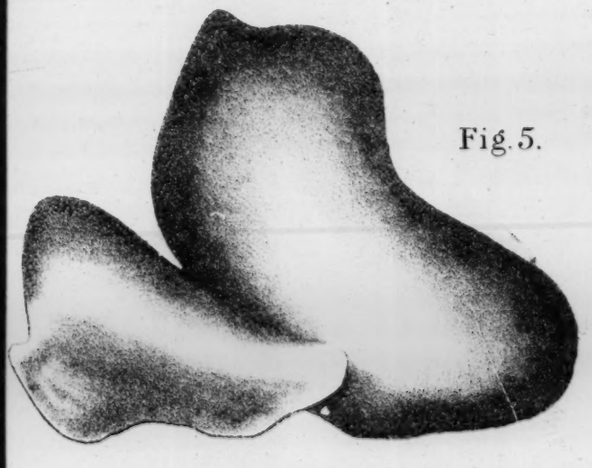


Fig. 5.

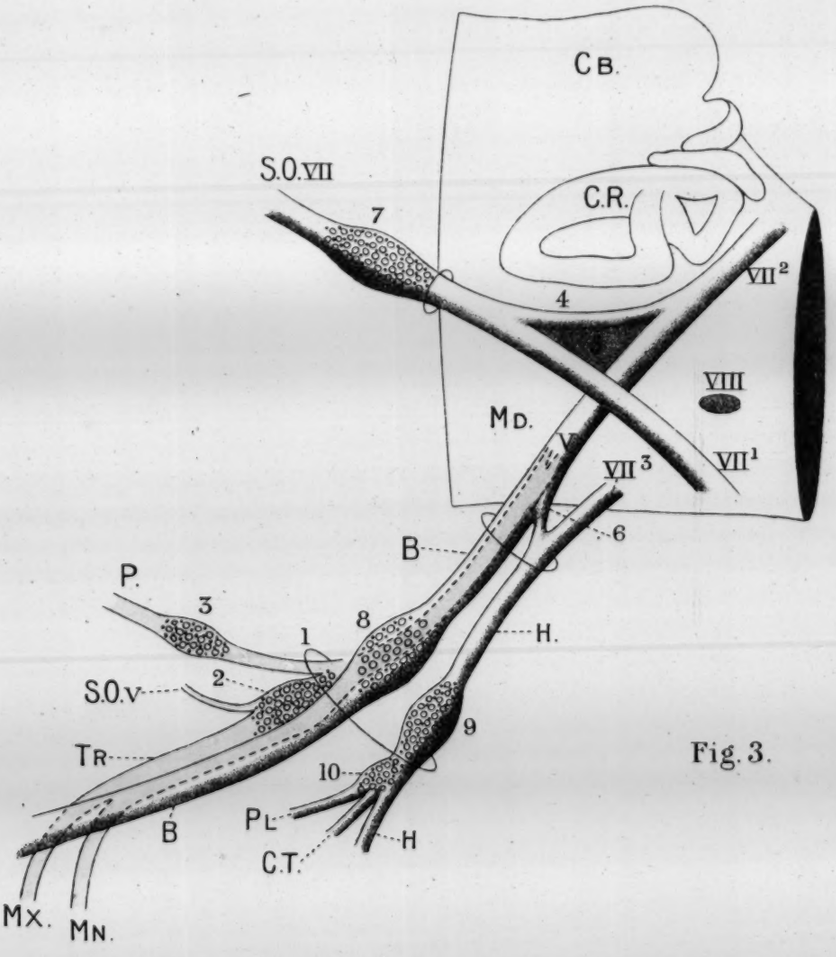


Fig. 3.

Cole. del. (Figs. 4 & 5, A. Scott, del.)

M.Farlane & Erskine. Lith.rs Edin.

XX.—*The Meteorology of Edinburgh.* By Robert Cockburn Mossman, F.R.S.E., F.R. Met. Soc. (With Three Plates.)

(Read 1st June 1896.)

PART I.

Introduction.

Since the foundation of the Scottish Meteorological Society in 1856, a mass of information regarding the climate of Edinburgh has been reduced and published in the Society's *Journal* from time to time, the data being furnished to that body by its local observers. In addition, numerous unreduced manuscript books of meteorological observations which extend back to the year 1764 are further available for discussion. In 1861 the late Principal Forbes communicated to this Society a paper on the "Climate of Edinburgh,"* two elements of climate being alone discussed, viz., temperature and rainfall, and for a period of but forty years. The reduction of the observations taken virtually without a break during the past 132 years was therefore desirable for the discussion of cyclical and other weather changes, for which records covering a long period are absolutely necessary. Through the kindness of the Councils of the Scottish Meteorological Society, the Royal Society of Edinburgh, and the Royal Meteorological Society, the loan of the manuscript registers kept in Edinburgh and its immediate vicinity was obtained.

The daily observations taken at Edinburgh from 1857 to the commencement of my series in 1886 were kindly copied from the original records by Miss J. H. Buchan of the Scottish Meteorological Society's office. For one or two short periods no observations were made in the city, but the missing values were deduced from the records of contiguous stations by Dr Buchan, to whom I have further to tender my best thanks for helpful advice and suggestions received from time to time in the progress of the paper. I am further indebted to Mr Charles Stewart, B.Sc., for assistance in the calculation of the thermal and hygrometric windroses and for other help in connection with the re-tabulation of some of the temperature observations. The following statement exhibits the data available for discussion, and it will be seen that, while the period covered by the inquiry extends over 132 years, the duplication of observations for certain periods lengthens the time embraced by the records to nearly 400 years.

* *Trans. Roy. Soc. Edin.*, vol. xxii.

NOTE.—The following contractions have been used to denote the elements observed, viz., T. for temperature, P. pressure, R. rainfall, W. wind direction, N. for weather notes, while C. indicates that all the foregoing data are given, and that the record is complete. M. in the reference column signifies that the register is in manuscript.

No. of Register.	Kept at.	Observer.	Years.	Hours of Observation.	Nature of Observations.	Remarks.	Reference.
I.	?	?	1731–36.	8 or 10 A.M. and 4 or 6 P.M.	C.	FORBES (*Trans. Roy. Soc. Ed.*, vol. xviii. p. 327) inclined to the belief that the observer was a medical man resident in the vicinity of the present Royal Exchange.	*Medical Essays and Observations*, published by a Society in Edinburgh, 5 vols., 3rd ed., 1748.
II.	...	...	1764–70.	8 A.M.	T.	...	Essays, *Phil. Soc. Edin.*, vol. iii.
III.	Hawkhill Ho.	JAMES HOY.	1764–76.	8 A.M. and 3 P.M.	C.	From Jan. 1771 to May 1776 the temperature was read at 8 A.M., noon, 2, 3, 4, 6, 8, and 10 P.M., and at midnight. Up to 1770 the temperature alone was taken. The rain was not measured from 1777–79.	M.
	St Andrew Sq. and Pleasance.	do.	1777–79.	8 A.M.	P. T. W. N.		
	Mertown.	do.	1780–June '81.	8 A.M.	C.		
IV.	Near the foot of Arthur's Seat.	?	1785–93.	Sunrise and noon.	T. P. R. N.	The temperature only was read twice a day. The hour at which the other observations were made is not stated, but was probably noon.	Tables are given *in extenso* in the monthly numbers of the *Edinburgh Magazine*, afterwards the *Scots Magazine*.
	Near the Castle.	...	1794–98.	do.	do.		
	At Barnton, 3½ miles west of Edinburgh.	...	1799–1817.	do.	do.		
V.	?	?	1787–1831.	8 A.M. and 8 P.M.	T. N.	The daily min. temp. was given after 1802.	*Edinburgh Advertiser*. Newspaper from which the observations were extracted.
VI.	Windmill St.	Prof. PLAYFAIR.	1794–99.	8 A.M., 2 P.M., 10 P.M.	C.	The values given are monthly means and extremes.	*Trans. Roy. Soc. Ed.*, vols. iv. p. 213, and v. p. 193.
VII.	Near George IV. Bridge.	ALEX. ADIE.	1795–1805.	8 A.M. and 8 P.M.	C.	FORBES, in his "Climate of Edinburgh," discusses the observations of temperature and rain. The daily max. and min. temperatures were not observed till 1821.	*Trans. Roy. Soc. Ed.*, vol. xxii. p. 327; *Edin. Jour. Science*, 1824–32; Original MSS., 1840–50.
	Canaan Cottage.	...	1821–31 and 1838–50.	10 A.M. and 10 P.M.	C.		
	Regent Terrace.	...	1832–37.	10 A.M. and 10 P.M.	C.		
VIII.	Coates Hall.	J. M'FARLANE.	1811–19.	?	W. N.	...	M.
IX.	St John's Hill and York Pl.	G. WATERSTON.	1797–1850.	9 A.M., 4 P.M. Midt.	C.	The rainfall, however, is given monthly for a few years only. The daily observations taken from 1808–16 are not known to be in existence, but monthly means have been preserved for this period.	M.
X.	Calton Hill Observatory.	?	1817–26.	...	C.	...	*In extenso* in the monthly numbers of *Scots Magazine*.
XI.	Leith.	J. COLDSTREAM.	1822–27.	9 A.M. and 9 P.M.	C.	The values for one or two years were published in *Edin. Phil. Jour.*	M.
XII.	Canonmills.	PAT. NEILL and F. FOGGO.	1822–27.	Morning and evening.	T. P. N.	...	M.
XIII.	?	Dr GAIRDNER.	1820–36.	8 A.M. till 1828, then 8 A.M. and 8 P.M.	T. P. N.	Interesting notes on epidemics and public health generally are given at the close of each month.	M.

No. of Register.	Kept at.	Observer.	Years.	Hours of Observation.	Nature of Observations.	Remarks.	Reference.
XIV.	Royal Society.	Librarian.	1838-76.	10 A.M.?	P. N. W.	No readings of the barometer were taken on Sundays, or holidays, but the missing values have been interpolated.	M.
*XV.	Princes St.	A. ADIE & SON.	1852-55.	9 A.M. and 3 P.M.	C.	Blanks occur once or twice.	M.
XVI.	Melbourne Pl.	Royal Engineers.	1853-56.	9.30 A.M. and 3.30 P.M.	C.	The values given are monthly means and extremes.	*Abstracts from Meteorological Observations taken at the Stations of the Royal Engineers.* Edited by Colonel Sir HENRY JAMES, R.E., F.R.S.
XVII.	Various.	Various.	1856-86.	9 A.M. and 9 P.M.	C.	These are the readings taken at the stations of the Scot. Met. Soc., and extracted from the schedules in the Met. Office, Edin.	M.
XVIII.	Blacket Pl.	R. C. MOSSMAN.	1887-95.	9 A.M. and 9 P.M.	C.	In addition to the ordinary observations automatic instruments record the fluctuations of pressure, temp., humidity, rain, and sunshine.	M.
XIX.	Charlotte Sq.	The late J. LESLIE, C.E., and Miss LESLIE.	1850-95.	Monthly.	R.	This is a very valuable rain register kept for nearly half a century. With this exception no registers of rain only have been quoted, but the results of all these extra stations will be given in Part II.	*Jour. Scot. Met. Soc.*, and M.

The present paper deals with mean values of the climatic elements for each day of the year, it being quite evident that many of the most interesting features of the pressure and other curves are wholly eliminated when *monthly* means alone are under consideration. The data, wherever possible, have been calculated for the fifty years 1840–51 and 1857–94, the means in a number of cases being thus made comparable *inter se*. The daily instrumental observations, being incomplete during the period 1852–56, could not be dealt with in this inquiry, but monthly means are available, so that there will be no hiatus when we come to the examination of monthly and annual averages. As regards the non-instrumental observations, which extend back without a break to the year 1770, daily values for the fifty years quoted above have not been given, but five-day totals will be found in Table XXXII., which are graphically shown for both periods in Plate III. It is not our intention to make any reference to the monthly means deduced from the daily values extending over periods ranging from 30 to 125 years, as tables of monthly and annual values will subsequently be available, based in most cases on observations extending over 132 years, particulars of which will be given in the second part of this inquiry.

* Since the above table was compiled, Mr G. J. SYMONS, F.R.S., has drawn my attention to a daily register of pressure and temperature kept at Edinburgh from 1847–51 by KENNETH M'KENZIE. See *Quart. Jour. of Agriculture*, July 1852, and *Farmers' Note Book*, No. xxvi. p. 402.

The tables which accompany the text have been derived by immense condensation from over one million observations, the re-tabulation of which was required as a necessary preliminary. The values were entered on special forms having 366 columns one for each day of the year and an extra one for February 29. After the daily and annual means were computed, the excess or defect of each daily value from the mean of the whole year was ascertained. The daily departures from the annual mean were then smoothed by BLOXAM's method, which consists in assuming the mean of the first, second, and third days to be the true mean of the second day; and so on, the average of continuous threes being calculated. Any sudden or accidental day to day difference is obviously eliminated by this method. The results presented are based upon an analysis of all the climatic elements; a most essential condition, since from such a comprehensive examination alone is it possible to show the mutual inter-relations which exist among the weather elements. The results are graphically shown in the plates which accompany the paper, while mean values for each of the seventy-three five-day periods will be found in Table XXXII.

Mean Barometric Pressure. (*See Tables I. and II.*)

The mean barometric pressure has been computed from observations made at the rooms of the Royal Society, Mound, from 1840–51 and 1857–61. From 1862 to 1884 the readings were made at Leith, 2 miles N.E. of the former station, while from 1885 to 1894 the observations were again made in Edinburgh. Each observation was first reduced to 32° and then to mean sea-level, while the instrumental correction, including index-error, was applied to each of the 18,500 values. To reduce the observations to standard gravity a further correction of +0·028 inch is necessary; this has not, however, been applied. The reduction of the Leith observations was kindly made under the direction of Mr R. H. SCOTT, F.R.S. No observations were made at this station on Sundays until 1868, but the missing readings have been interpolated by differentiating with Edinburgh. The hour of observation was 10 A.M. till 1861, 8 A.M. till 1884, and 9 A.M. since. The following are the extreme mean daily (not absolute) pressures on the average of fifty years :—

Month.	Highest Inches.	Date.	Lowest Inches.	Date.	Range Inches.
January, . .	29·878	12	29·670	30	0·208
February, .	·921	23	·704	1	·217
March, . .	·935	3	·746	31	·189
April, . .	·983	30	·764	2	·219
May, . .	30·013	13	·815	18	·198
June, . .	29·992	16	·880	9	·112
July, . .	·932	15	·820	25	·112
August, . .	·890	18	·789	8	·101
September, .	·972	13	·772	29	·200
October, . .	·913	4	·707	24	·206
November, .	·905	9	·628	26	·277
December, .	·948	27	·729	19	·219
	30·013	May 13	29·628	Nov. 26	0·385

Looking at the smoothed means in Table II. it will be seen that pressure is above the annual average on 195 days and below it on 169 days. The most pronounced maximum occurs from April 7 to July 3, during which time pressure is below the mean on only one day, viz., May 18. The period of low pressure is from September 26 to February 11, but anti-cyclones occur from time to time, the longest spell of uninterrupted low pressure being from October 6 to November 6. The unsteadiness of the barometer is remarkable, considering that a period of fifty years is under discussion, there being no less than twenty-seven well-defined troughs and a similar number of crests in the air waves, the mean height of the barometer during these being 29·808 inches and 29·909 inches respectively. The cyclonic and anti-cyclonic periods will be examined in detail when the climatic features which accompany them are under discussion, but attention may be here called to the remarkable barometric depression in November which is the most noteworthy feature of the pressure curve. The mean barometric pressure on November 18 for the period under review is 29·902 inches, after which it falls slowly to 29·831 inches on the 21st. Pressure then diminishes with great rapidity, and with one or two minor oscillations falls to the minimum on November 26, when the low value of 29·628 inches is attained. A rapid rise then sets in, which culminates on December 2 in a reading of 29·922 inches. The following table shows the mean pressure for each day of the period November 18 to December 2 on the average of fifty years, as well as mean values for Edinburgh and Greenwich for the thirty-three years 1861–93. The Greenwich values were extracted from the detailed annual volumes of *The Greenwich Magnetical and Meteorological Observations*, and are the mean of twenty-four hourly observations, while the Edinburgh readings were made at 8 or 9 A.M.

Date.	Edinburgh, 50 Years. At 32° and Sea-Level.	Edinburgh, 33 Years. At 32° and Sea-Level.	Greenwich, 33 Years. At 32° and Sea-Level.
	Inches.	Inches.	Inches.
November 18	29·902	29·937	30·023
„ 19	·842	·888	·004
„ 20	·841	·930	·023
„ 21	·831	·893	29·975
„ 22	·655	·677	·851
„ 23	·695	·718	·859
„ 24	·716	·735	·857
„ 25	·637	·619	·774
„ 26	·628	·605	·778
„ 27	·706	·667	·850
„ 28	·759	·772	·915
„ 29	·734	·764	·884
„ 30	·791	·774	·884
December 1	·836	·821	·912
„ 2	·922	·935	30·004

Hence the returns from the two places are substantially the same, the barometer

naturally standing higher at the southern station. The Edinburgh registers have been examined for various sets of years, with the result that this great November wave invariably manifests itself about the 26th of the month. The barometric fall, as might be expected, is greater in the north than in the south of our islands, and probably embraces the whole of Western Europe. The depression is apparently not associated with steepening gradients, as there is no marked increase in the frequency of gales during the passage of the low-pressure area.

Temperature.

The average maximum, minimum, and mean temperature, as well as the daily range and daily variability of temperature, have been determined from the observations made during the fifty years 1840–51 and 1857–94, the latter set of observations being those taken at the various Edinburgh stations of the Scottish Meteorological Society. From 1840 to 1851 the observations were made at Canaan House, Grange, by the late ALEX. ADIE, Esq., F.R.S.E. I am indebted to Mr WILLIAM J. MENZIES, W.S., for the loan of this important register. All the values were corrected to a height of 250 feet above mean sea-level.

The mean temperature of each day of the year has also been calculated on the average of 100 years.

The observations from 1770 to 1779 were taken by Mr HOY, the station being Hawkhill House till 1776 and afterwards at St Andrew Square and Pleasance. The readings utilised were those made at 8 A.M. From 1795–1804 the observations were made at Merchant Court* by Mr ADIE, the hours of observation being 8 A.M. and 8 P.M. From 1811–20 the 8 A.M. and 8 P.M. values printed *in extenso* in the *Edinburgh Advertiser* were employed. From 1821–30, and from 1831–40, the daily means are those deduced from the mean of maximum and minimum thermometers, the observations being also made by Mr ADIE. The mean daily temperatures for each of the decenniums 1795—1804, 1821–30, and 1831–40 were taken from FORBES' "Climate of Edinburgh";† the means for the ten years ending 1804 being first brought to the mean of the maximum and minimum by the following corrections, which were obtained by comparing ADIE'S 8 A.M. and 8 P.M. values with a table of adopted mean temperatures for the years in question.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
+0°·8	+1°·0	+1°·3	+1°·3	+0°·8	+0°·7	+0°·8	+1°·0	+1°·0	+0°·6	+0°·4	+0°·4

It may be remarked that the means for the decennium 1795–1804 include the returns for the first six months of 1805. This, however, does not affect the results, ten-year means having been entered in the table from which the 100-year average was obtained. The period embraced in the discussion is thus really 100½ years.

* This locality is now extinct, but it was in the vicinity of George IV. Bridge.

† *Trans. Roy. Soc. Edin.*, vol. xxii. pp. 348–49.

In a recent number of the *Scottish Meteorological Society's Journal* (vol. ix. p. 224) Dr BUCHAN gave a paper on the "Mean Temperature of the N.E. of Scotland from 1764–1894," the means being corrected to an elevation of 100 feet above the sea. From 1764 to 1781 the observations were made by Mr HOY, whose 8 A.M. readings have been utilised for the decennium 1770–79. A comparison of Dr BUCHAN'S adopted means with the 8 A.M. values gave the following corrections to be applied in order to bring them to the average of maximum and minimum thermometers at a height of 250 feet above mean sea-level.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
+1°·0	+1°·2	+0°·8	+0°·3	−0°·3	−0°·3	−0°·2	+0°·3	+0°·3	+0°·7	+0°·7	+0°·9

The decennial means with the above corrections applied were then entered in the table. Similarly the means of the 8 A.M. and 8 P.M. observations made from 1811 to 1820 were first compared with FORBES' adopted temperatures for the above ten years and then with my own table of Edinburgh mean temperatures. The corrections, in both cases, are virtually the same, showing that FORBES' interpolated values for the years in question deduced by differentiation from the Dunfermline register, give a very close approximation. The following were the corrections applied:—

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
+1°·2	+1°·9	+2°·4	+3°·0	+2°·8	+2°·7	+2°·4	+2°·2	+1°·8	+1°·6	+1°·4	+1°·3

In view of the somewhat anomalous corrections given above a careful examination was made of the adopted temperature values from which they were deduced. In this connection the observations made at Gordon Castle, Kinfauns Castle, and other places in Scotland were gone over and compared with the Edinburgh values, the accuracy of which they confirmed. It will be seen that the above table of corrections differs materially from that given for the reduction of ADIE'S 8 A.M. and 8 P.M. readings to mean temperatures. The difference between the two tables may be accounted for by the assumption that ADIE'S thermometer was slightly exposed to radiation during several months of the year, while the *Edinburgh Advertiser* observations were probably made in a shady court.

The decennial means for the period 1841–50 given by FORBES have not been utilised, as an examination of ADIE'S original register showed several blanks in the observations. These were made good by interpolating values for the missing days from other Edinburgh registers. The decennial values for each day of the year were then tabulated and the means entered in the table. Hence Table V., showing the mean temperature of each day of the year at Edinburgh on the mean of 100 years, is made up of seventy years' maximum and minimum readings obtained from registering thermometers, while during twenty years observations were made at 8 A.M. and 8 P.M. from ordinary thermometers, similar readings being taken for ten years at 8 A.M. only. These values, as already shown, have been brought to the mean of the maxima and minima, so as to make the results strictly comparable.

The following table shows the highest and lowest daily temperatures on the mean of 100 and 50 years respectively :—

	Mean 100 Years.					Mean 50 Years.				
	Highest.	Date.	Lowest.	Date.	Range.	Highest.	Date.	Lowest.	Date.	Range.
	°		°		°	°		°		°
January, . .	38·38	20	35·86	8	2·52	39·32	30	36·28	6	3·04
February, . .	39·52	23	37·61	3	1·91	40·12	18	36·75	9	3·37
March, . .	43·02	31	38·86	2	4·16	43·36	31	38·71	1	4·65
April, . .	47·47	30	42·62	1	4·85	46·80	30	43·18	1	3·62
May, . . .	53·36	31	47·16	2	6·20	53·20	30	46·69	4	6·51
June, . .	58·18	29	53·65	3	4·73	58·29	28	53·40	3	4·89
July, . . .	59·20	15	57·29	1	1·91	59·11	15*	57·48†	1	1·63
August, . .	59·23	8	56·21	31	3·02	59·17	12	55·82	31	3·35
September, .	56·46	2	51·08	30	5·38	57·06	2	51·13	30	5·93
October, . .	50·71	1	43·83	29	6·88	50·91	1	43·92	26	6·99
November, .	44·60	1	39·06	25	5·54	44·75	1	39·33	30	5·42
December, . .	39·86	4‡	36·42	27	3·44	40·88	5	36·99	23	3·89
	59·23	Aug. 8	35·86	Jan. 8	23·37	59·17	Aug. 12	36·28	Jan. 6	22·89

* And 21. † And 4. ‡ And 5.

It will be seen, from Tables III. and V., that the mean annual temperature of Edinburgh deduced from the observations of 50 and 100 years respectively differs by only half a tenth of a degree. Owing to the great frosts experienced at the end of the last and the beginning of the present century, the mean temperature of the winters was more than half a degree lower than the values calculated from the shorter average, but during the other seasons there was a slight excess during the longer period.

The coldest day on the mean of 100 years is January 8, with an average temperature of 35°·86, while the warmest is August 8, with a mean of 59°·23, showing an extreme range in the daily temperatures of 23°·37. For the fifty years the coldest day is January 6, and the warmest August 12, with mean temperatures of 36°·28 and 59°·17 respectively, the annual range being 22°·89. On smoothing the curves it is seen that the warmest day of the year clearly falls on July 15, and the coldest on January 8.

Looking at the smoothed values in Tables IV. and VI. it will be observed that the temperature on the mean of fifty years rises permanently above the annual average on May 6 and remains above it till October 18, while on the average of 100 years the respective dates are April 29 and October 18. On the long average, temperature is thus above the annual mean on 173 days, and below it on 191, being just the average on one day, viz., October 19.

Mean Maximum Temperature.

The following table shows the highest and lowest mean maximum temperatures on the average of fifty years. (See Table VII.)

	Highest.	Date.	Lowest.	Date.	Range.
	°		°		°
January,	44·6	30	41·0	9	3·6
February,	45·4	23	41·7	9	3·7
March,	50·7	31	44·0	1	6·7
April,	54·7	29	50·2	14	4·5
May,	61·5	31	54·4	4	7·1
June,	66·1	21	60·8	3	5·3
July,	66·8	21	64·8	4	2·0
August,	66·6	14	63·1	31	3·5
September,	63·8	2	57·4	31	6·4
October,	57·6	1	49·5	30, 31	8·1
November,	50·0	3	44·4	30	5·6
December,	45·8	5	41·8	23	4·0

Hence the range of temperature between the warmest day, July 21, and the coldest, January 9, is 25°·8.

Mean Minimum Temperature.

Table IX. shows the average minimum temperature of fifty years for each day of the year. The monthly extremes are as follows :—

	Highest.	Date.	Lowest.	Date.	Range.
	°		°		°
January,	34·8	31	30·9	21	3·9
February,	34·9	18	31·8	9	3·1
March,	36·1	31	33·1	10	3·0
April,	39·5	21	35·9	1	3·6
May,	45·2	30	38·8	2	6·4
June,	50·6	27	45·8	1	4·8
July,	51·7	15	49·8	10	1·9
August,	52·3	8	48·5	31	3·8
September,	50·3	2	44·7	22	5·6
October,	44·3	1	37·5	26	6·8
November,	40·0	1	34·2	30	5·8
December,	35·9	5	32·1	27	3·8

The extreme range is thus 21°·4, or 4°·4 less than the corresponding range between the maxima. The mean maximum (Table VIII.) is above the annual average from April 26 to October 14, but the minimum (Table X.) does not get above the annual mean until May 12, and remains above it till October 19.

Mean Daily Range.

The mean daily range of temperature is shown in Table XI., the values there given being the differences between the mean maximum and minimum temperatures (Tables VII. and IX.).

The following are the monthly extremes :—

	Greatest.	Date.	Least.	Date.	Difference.
	°		°		°
January,	11·2	26	8·8	31	2·4
February,	11·3	26	9·5	10	1·8
March,	14·6	31	10·5	3	4·1
April,	16·1	29	13·0	8	3·1
May,	17·0	31	14·4	11	2·6
June,	17·0	20	14·0	25	3·0
July,	16·3	16, 17	13·9	25	2·4
August,	15·9	1	13·1	21	2·8
September,	15·8	8	12·0	24	3·8
October,	13·3	1	10·5	24	2·8
November,	11·4	7	8·7	20	2·7
December,	12·1	2	8·3	7	3·8

The mean daily range of temperature is above the annual average from March 21 to October 2, if we except the five days, March 26–28 and September 24–25, when it is slightly under the mean.

Variability of Temperature.

The variability of temperature has been computed for each day during the fifty years 1840–51, 1857–94. The first stage of the operation was to strike the arithmetical mean of the maximum and minimum temperatures. Then the day to day differences in the mean temperature of successive days were computed and entered into 366 columns corresponding to the 365 days in the year, and the extra day in leap year. These values were then added up, the gross totals being given in Table XIII. under the heading of "Cumulative Temperature Variability." Cumulative values have been given instead of means, the variation being extremely small, as will be apparent from the following table showing the highest and lowest mean variabilities in each month.

	Highest.	Date.	Lowest.	Date.	Range.
	°		°		°
January,	4·2	1	2·6	22	1·6
February,	3·8	2	2·2	25	1·6
March,	3·5	17	2·2	25	1·3
April,	3·3	12	2·1	8	1·2
May,	3·3	5	2·3	12	1·0
June,	3·6	4	2·1	14	1·5
July,	3·1	18	2·0	25	1·1
August,	2·9	12, 26, 27	1·9	24	1·0
September,	3·1	27	2·2	13	0·9
October,	3·9	25	2·2	7	1·7
November,	4·0	30	2·3	11	1·7
December,	3·9	29	2·7	10	1·2

Hence the greatest variability, 4°·2, occurs on January 1, and the least, 1°·9, on August 24. Looking at Table XIV. it will be seen that the variability is, broadly speaking, above the annual average from October to March, and below it during the other six months of the year, falling to an annual minimum in July and August. The variability of temperature seems to depend in no inconsiderable degree on the amount of vapour present in the air. When the quantity of vapour is small, the tendency for temperature to change from day to day reaches a maximum, but when the amount is large, the conserving influence exerted by it on the temperature of the air is very apparent. The variability of temperature during the winter is further increased by the prevalence of rapidly moving cyclones and their accompanying anti-cyclonic systems, with their different temperatures and humidities.

Direction of the Wind.

The number of times the wind blew from each direction has been determined for each day of the year on the mean of 100 years (see Tables XV. and XVI.). The observations utilised were taken from 1770–79 and from 1800 to 1894, with the exception of the years 1809, '10, '37, and '38, for which we have only monthly summaries. The observations utilised were those contained in registers III., VII., IX., XIV., XVII., and XVIII.; the hour of observation varying from 8 to 10 A.M., the direction being usually observed to eight points. For some years the direction was given to sixteen points, but the values were resolved to eight points by halving the eight intermediate points between the octants. No attempt has been made to calculate the mean direction from the observations, LAMBERT's formulæ yielding results that are obviously erroneous unless the air movement from the different octants is known.

The seasonal variation in the percentage frequency of the various winds is well marked. Perhaps the most interesting feature is the difference between the W. and S.W. winds, the former of which are at a maximum in August, and the latter in February. This is probably due to the fact that in February the dominating factor is the low-pressure area located over Iceland, while in August the lowest barometer is found over India.

Rainfall.

Table XVII. gives the total rainfall collected during eighty-eight years on each day of the year, the series being a composite of several registers. From 1770–76 the observations were made at Hawkhill House by JAMES HOY, who also kept a gauge during the year 1780. From 1785 to 1817 the rain tables given monthly in the *Edinburgh Magazine* (afterwards the *Scots Magazine*) have been utilised. The station was "near the foot of Arthur's Seat" till 1793, "within one mile of the Castle of Edinburgh" from 1794 to 1798, and thereafter at Barnton, three and a half miles west of Edinburgh, till 1817. The values from 1824 to 1831 were obtained from the meteorological register kept at Canaan House by ALEX. ADIE, optician, and F.R.S.E., the daily observations being published in the *Edinburgh Journal of Science*. Since the establishment of the Scottish Meteoro-

logical Society the rain values from the various stations reporting to that body have been employed, the period being from 1857 to 1895 inclusive.

The following table shows the least and greatest rainfalls in every month :—

			ins.			ins.		
In January the sums vary from			8·4	on the	26th	to 2·6	on the	3rd
„ February	„	„	8·6	„	2nd	„ 2·5	„	23rd
„ March	„	„	6·5	„	9th	„ 1·9	„	13th
„ April	„	„	7·6	„	21st	„ 3·4	„	12th
„ May	„	„	8·8	„	24th	„ 2·3	„	3rd
„ June	„	„	9·0	„	4th	„ 3·6	„	20th
„ July	„	„	10·3	„	5th	„ 5·1	„	4th
„ August	„	„	13·4	„	3rd	„ 4·2	„	23rd
„ September	„	„	12·7	„	17th	„ 3·2	„	16th
„ October	„	„	10·9	„	20th	„ 3·6	„	2nd
„ November	„	„	11·3	„	5th	„ 3·1	„	11th
„ December	„	„	10·7	„	9th	„ 3·8	„	25th

It will be seen that the wettest day of the year is August 3, with a fall of 13·4 inches; the next in order being August 13 and 14. The day in the year with the smallest downfall is March 13, with 1·9 inch, the next driest being May 3 and February 23. By far the wettest period is that embraced in the seven days ending with August 18, the period distinguished by the least fall being the week ending with March 27. The totals for these two weeks are respectively 77·53 and 24·04 inches. Great differences are observable in the sums of consecutive days, the fall on August 3, for example, being 13·4 inches, but on August 2 only 5·2 inches fell. It is thus evident that a very long period indeed is required to give daily mean rainfalls; probably observations extending over two centuries would be necessary to define the daily fall with accuracy.

Table XIX., giving the number of times a rainfall of 0·01 inch was registered in each day of the year during eighty-eight years, must be regarded in the light of a tolerable approximation to the truth, it being quite evident that many of the older observers systematically neglected to measure slight rainfalls, but allowed several small amounts to accumulate. Every effort has been made to detect and throw out such erroneous entries, but a number must obviously remain.

The number of rainy days in every month on the total of eighty-eight years vary as follows :—

	Greatest.	Date.	Least.	Date.
January,	46	29	28	14
February,	48	2	33	5, 20
March,	45	6	25	8
April,	43	22	27	9
May,	45	17, 28	28	15
June,	47	24	27	1
July,	47	19	34	17
August,	55	13	34	19, 21
September,	49	21	33	16, 18
October,	55	10	36	27
November,	55	5	32	11
December,	49	22	29	24

Hence the frequency of rainfall is at a maximum on August 13, October 10, and November 5, on each of which dates rain has fallen on fifty-five of the eighty-eight years under review, while the smallest number of rainy days, viz., twenty-five, occurs on March 8.

Sunshine.

Daily sunshine values have been calculated for thirty years. From 1861 to 1876 the observations were made at Inveresk, 6 miles E. of the city. From 1877 to 1885 the observer was Mr BLACKWOOD, Cumin Place. No instrument was in use during the above periods, the method adopted being to estimate the total sunshine recorded during each day. From July 1890 to June 1895 the records are derived from a CAMPBELL-STOKES sunshine recorder in use at my station at Blacket Place. Owing to the shortness of the period and the comparative looseness of the method of observing this element of climate during the greater part of the period, the values given in Tables XX. to XXIII. must only be regarded as tolerable approximations.

Table XX. gives the mean number of hours the sun shone on each day of the year, but in order to make the results strictly comparable the mean percentages which the amounts recorded formed of the total possible sunshine for each day were computed. The table given in the last edition of the Smithsonian Tables was the one from which the total possible sunshine for Edinburgh was obtained. No allowance has been made for the loss of sunshine which occurs near the time of sunrise and sunset owing to haze at the horizon.

The following are the variations in the mean percentage of possible sunshine from month to month. (See Table XXI.)

	Greatest Percentage of Possible.	Date.	Least Percentage of Possible.	Date.	Range.
January, . . .	35	25	13	4	22
February, . .	35	8	20	27	15
March, . . .	42	8	23	28	19
April, . . .	37	30	23	5	14
May, . . .	38	24	24	17	14
June, . . .	35	21	22	3	13
July, . . .	38	17, 20	22	26	16
August, . . .	38	23	24	8, 17	14
September, . .	39	11	20	22	19
October, . . .	36	2, 10	19	30	17
November, . .	35	10, 20	17	24, 27, 28	18
December, . .	26	23	12	18	14

Hence on the sunniest day of the year, viz., March 8, not half the possible sunshine is recorded, while on December 18 we obtain only 12 per cent. of the total possible. There is not much variation in the daily values from March to October, but the dull period is well marked, extending from the middle of November to the end of January.

Table XXIII. shows the number of times sunshine was registered on each day of the year for the thirty years. May 27, June 19, and September 6 had not a single sunless day in this period, but December 4 was sunless on seventeen occasions.

Auroras.

Table XXIV. gives the number of times the aurora was observed on each day of the year for eighty-one years, the periods being 1773–81, 1817–52, and 1859–94.

This meteor does not seem to have been systematically recorded during the other years.

The number observed in all was 332, being an average of four a year. Their distribution throughout the year shows two maxima and two minima, the primary maximum extending from about September 21 to November 23 and the secondary from February 18 to April 20. During the whole eighty-one years, only two auroras were observed from May 22 to July 26.

Snow.

The number of days on which snow fell for each day of the year is given in Table XXV., the period under discussion being the 125 years 1770–1894. For short periods that embraced in the nineteen days ending with February 12 is the snowiest, another maximum occurring from March 6 to 16. Snow is comparatively uncommon after April 2, but a slight increase is observable from April 9 to 12, or about the time of "the borrowing days." The infrequency of snowstorms about the middle of December is of interest in connection with the retardation of the autumnal fall of temperature at that time. No snow fell in the months of June, July, August, and September during the 125 years under review.

Hail.

The number of times hail fell is given for each day of the year in Table XXVI. The annual period is well marked, the phenomenon being essentially a spring one extending over the nine weeks ending May 10. The minimum is reached in August. It is probable that true hail is of rare occurrence, most of the falls being cases of graupel or soft hail.

Thunderstorms.

Table XXVII. shows the distribution of thunderstorms through the days of the year. These phenomena temporarily increase after the termination of the cold period about May 13, but the summer frequency does not begin until a fortnight later. The time of absolutely greatest activity is from July 3 to August 13, after which few cases are recorded. The minimum is in November and December, no case having been observed from November 17 to December 5 during the 125 years.

Lightning without thunder, Table XXVIII., is a comparatively rare phenomenon, only eighty-five cases having been recorded during the sixty-one years during which this meteor was observed. As compared with thunderstorms, sheet lightning shows a relatively

greater frequency during winter, but there is no pronounced maximum. It is seldom seen in spring, only fourteen cases being reported from March to June inclusive.

Gales.

Table XXIX. shows the distribution of gales throughout the year. The absolutely stormiest time is from January 19 to February 6, and the calmest from June 26 to July 30. The popular belief in the prevalence of storms at the spring or the autumnal equinox is not supported by the data under consideration.

Fog or Mist.

The preparation of this table (XXX.) has been a matter of much labour, owing to the different ideas prevailing among the observers as to what constitutes fog or mist. It is quite evident that for some periods "haze" was entered as fog. All such erroneous entries as could be detected were eliminated, but owing to the lack of uniformity in the observations, an element of error is introduced. The foggiest periods are during the cold weather in January, viz., from the 9th to the 14th, and from April 22 to June 26, or during the time when easterly winds are most prevalent. The annual minimum is in February.

Climatic Features of the Winds.

It has been proved by meteorologists that the weather prevailing at any given time at a place is the result of the distribution of pressure at the time. Now, since the distribution of pressure regulates the direction of the wind it follows that if we wish to see clearly the effect of different pressure types on the weather that the way to do so is to analyse the climatic features of the various winds. We have accordingly, with the able assistance of Mr Charles Stewart, B.Sc., calculated the mean temperature, mean relative humidity, average amount of vapour in a cubic foot of air, and mean percentage of sunshine for the various winds.

The observations utilised for this purpose, over 10,000 in number, were taken at my station in the south side of Edinburgh 254 feet above the sea, the hours of observation being 9 A.M. and 9 P.M. The values given are the mean of the seven years ending with June 1894. (See Tables XXXIII. to XXXVI.)

As regards sunshine the values are for the five years ending July 1895, and will be found in the last volume of the *Scottish Meteorological Society's Journal.**

Temperature.—The warmest winds at Edinburgh are S., S.W., and W. The warmest direction is S.W., except in August and September, when it changes to W. The coldest winds, on the other hand, are N. in spring, autumn, and winter, and E. in summer. S.E. winds are characterised by unusually low temperatures in December and January. That severe frost often occurs with the wind in question has been pointed out by the Rev. Fenwick Stow in an interesting and suggestive paper published in the *Royal Meteorological Society's Quarterly Journal.*†

* Vol. x. p. 159.

† Vol. xvii. p. 176.

In spring and summer there is a well marked tendency for warm weather if the wind be calm or from the S.E. or N.W. During autumn and winter, low temperatures are experienced when these winds occur. The explanation is probably to be found in the considerable stretch of land traversed by S.E. and N.W. winds before reaching Edinburgh. During winter the temperature over these districts is low, owing to terrestrial radiation, while in summer the temperature inland is high.

Humidity.—The dampest winds are those from the E., N.E., and S.E., which blow off the North Sea, calms also having a high percentage of humidity. The driest wind is the N.W., except in winter, when the S.W. takes its place. The S.E. wind is a dry one in the early summer.

Vapour in a Cubic Foot of Air is at a maximum with S.W. winds and at a minimum when the direction is N. The S. wind has a remarkably large amount of water vapour present in July, August, and September, this being doubtless due to its high temperature.

Sunshine is most prevalent with winds from the N.W., W., and N., while but little is recorded with winds from an easterly quarter. When the air is calm during winter, sunless weather predominates, but fine weather prevails in summer with a calm atmosphere.

General Remarks.—The climatic features of the various winds at Edinburgh depend in no inconsiderable degree on whether they have blown over the land or over the sea; land winds being sunny, and dry at all seasons, warm in summer and cold in winter. Sea winds, on the other hand, are cold, damp, and sunless at all seasons of the year, the conditions varying according to the relationship existing between the temperature of the land surfaces and that of the contiguous expanses of water. For example, in spring and summer when there is little difference between the temperature of the North Sea and its western shores, a rapid increase of temperature being then in progress, the easterly winds at Edinburgh are comparatively sunny and warm; but in autumn and winter when the above conditions are reversed, the weather experienced is cold, dull, and humid.

On the General Climatic Characteristics of the Months at Edinburgh.

We have referred to the fact that the phenomena which are, in the aggregate, designated "weather," depend on the distribution of pressure over Western Europe at the time. When the barometer, for example, is high to the north of our islands and low to the south we have easterly winds; when the reverse conditions of pressure prevail, winds from the west predominate. The polar and equatorial air currents, as has been shown, are accompanied by totally different phenomena as regards temperature, humidity, rain, sunshine, and so on.

An examination of the data which are graphically projected on the plates clearly shows that certain definite weather types tend to recur from year to year at approxi-

mately the same time. It is not our intention to attempt to demonstrate the general causes concurring in these periodic phenomena, but rather to point out the inter-relations and inter-dependence of the various climatic elements during the passage of the different weather types. As the daily means are computed for various periods, attention can only be drawn to some of the more prominent recurring weather types, which are salient features of the curves.

January.

The most pronounced feature of the meteorology of the month is the cold period which culminates on the 9th, this being associated with a tendency to anti-cyclonic conditions, viz., relatively high pressure, little sunshine, scanty precipitation and that chiefly in the form of snow. Few gales are experienced, fog being consequently in excess. About the time of greatest cold there is a marked increase in polar winds, the equatorial current blowing with diminished frequency.

During the second half of the month pressure gives way, falling after one or two slight recoveries to a minimum at the end of the month, with a marked increase in W. and S.W. winds. Gales now rise to their annual maximum, and are accompanied by considerable precipitation, the rainfall being well above the annual mean after the 24th. Temperature shows a rise from a secondary minimum after the 21st.

February.

During the first twelve days of the month pressure is low, temperature also showing a fall from the 5th to the 9th. Gales fall rapidly from the maximum, while the snowfall also exhibits a diminution. Rainfall is above the mean at the beginning of the month but decreases in quantity until the 7th. During the first half of the month S.W. winds are well above the average. During the second half of February pressure is, on the whole, high, the anti-cyclonic type being well defined, with few gales and slight precipitation. E. winds begin to show an increase after the 18th. A shallow depression prevails during the last three days of the month with an augmented rainfall and lessened sunshine. A fall of temperature occurs from the 23rd to the 27th.

March.

The month opens with high pressure and sunny, dry weather, the daily range of temperature showing a distinct increase owing to the increased clearness of the skies. S.W. winds decline, while the N. and N.W. currents gain strength, gales from these quarters being frequent. After the first week a fall in pressure takes place, the minimum occurring on the 11th, after which the barometer rises till the 22nd, when snow showers and gales become infrequent, although a well-defined increase is observable in the frequency of hail showers. At the close of the month a rapid rise in

temperature is in progress, the increase being unequally partitioned between the day and night values, the maximum temperatures rising more rapidly than the minima.

April.

Low pressure prevails at the beginning of the month, during the continuance of which polar winds blow with diminished frequency. An interruption in the vernal rise of temperature known as the borrowing days occurs about the 10th, the fall of temperature being greater during the night than during the day, pointing to increased terrestrial radiation. At this time pressure is high, winds from the N.E. and E. being at a temporary maximum, while those from S., S.W., and W. are well below their mean frequency. Snow and hail showers exhibit a decided rise after the 5th. Throughout the last three weeks pressure is high, except for a slight fall culminating on the 21st, which is accompanied by a considerable rainfall, while gales shoot up to their average annual frequency, thereafter to remain steadily below it for four and a half months. During the prevalence of the strong winds, fog is uncommon. After the 21st, pressure rises rapidly, hail showers increase with the N.W. winds which usually blow in the rear of a cyclonic disturbance. A rapid fall of temperature also occurs. Westerly winds fall to their annual minimum about the 26th.

May.

Pressure is well above the mean during the first fourteen days, after which it falls quickly till the 18th, showing an equally rapid recovery in the four days immediately succeeding. E. and N.E. winds are at their annual maximum about the 10th of the month, pressure being then very high, although the rainfall is considerable. A slight fall of temperature occurs at this time. Fog now becomes frequent, thunderstorms also showing an increase, but hail showers are few, the values falling permanently below the annual mean at the close of the month. Rainfall is, on the whole, below the average, sunshine being abundant, except during a period of low pressure about the 15th. Temperature rises rapidly after the temporary interruption about the 10th.

June.

Pressure is high throughout the month, the anti-cyclonic tendency being at a maximum. Thunderstorms now become comparatively frequent, while the prevailing easterly winds bring with them an increased amount of fog. E. winds diminish somewhat from the 2nd to the 9th, after which there is little variation. The daily range of temperature reaches the annual maximum on the 20th, the increased difference between the day and night values being almost entirely due to the higher day temperatures which occur at this time. From the 20th to the 24th the maxima show a decided fall and the minima a less marked one; in other words, there is a distinct tendency for cloudy weather about this time. At the end of the month another well-marked fall of temperature takes place, during an increase in the frequency of N.E. and E. winds. The

sudden abatement of thunderstorms during this interruption of temperature is of interest.

July.

During the month there are two periods characterised by low and high pressure, each of which is associated with well-marked climatological features. The month opens with pressure above the mean, but falls to a minimum on the 7th, about which time thunderstorms rise to their annual maximum with torrential rains. During the first week there is a decided decrease in winds from the N., N.E., and E., while a corresponding increase is observable in winds from the W. The first high-pressure area embraces the ten days ending with the 18th, in the middle of which period temperature rises to the annual maximum on the 15th. Low pressure prevails from the 18th to the 26th, during which period E. winds increase, a point to be noted in connection with the excessive rainfall at the time. Temperature during the passage of the low pressure area continues to fall slowly. The month closes with high pressure, although with rainfall well above the annual mean.

August.

Throughout the month pressure is on the whole low and steady. The most prominent low-pressure period extends over the first half of the month, towards the close of which an enormous increase of rainfall takes place, known in Scotland as the Lammas floods. The absolutely wettest day of the year on smoothing the curve is August 13, the precipitation being then 96 per cent. above the annual mean. About this time a curious increase in the frequency of S.W. winds takes place, the W. wind for the time blowing with diminished frequency. A secondary maximum of temperature culminates on the 13th of the month, the temperature of the sea reaching its annual maximum at this time. After the middle of the month pressure rises slowly, the torrential rains abate, in connection with which the rapid decline of thunderstorms is of interest, electrical disturbances being of comparatively rare occurrence during the second half of the month. At the close of the month W. winds blow with greater persistence than at any other period of the year.

September.

During the greater part of September the tendency is for the anti-cyclonic type of pressure, which is most pronounced from the 11th to the 20th. Calms are now at their annual maximum. Rainfall is still above the mean, but shows a distinct fall from the previous month. The maximum temperature shows a rapid fall after the 13th, which does not appear in the minimum temperatures until the 16th; the fall ceases in both cases on the 22nd, after which a slight rise occurs, due apparently to the greater frequency of westerly winds at the time. During the rapid fall of temperature

referred to above there is little sunshine, which accounts for the comparatively small diurnal range in the temperature values. The month closes with a low barometer, gales now showing an increase.

October.

Pressure is low throughout, rainfall being well above the mean during the first three weeks, with the exception of a few days about the 16th. Gales show an increase after the 7th and are at a maximum about the 20th. This period is noteworthy as having more rainy days than any other time of the year, although the downpours are not of such a torrential character as in July and August. The winds during the month present few features of interest, although a number of small and unimportant oscillations take place from time to time. The excess of N. and S.E. winds is perhaps the most interesting, the latter in connection with the increased frequency of gales. At the close of the month pressure rises slightly, the rainfall diminishing about the time. Temperature falls steadily throughout with few and unimportant interruptions.

November.

During the first week pressure is below the mean, but is well above it in the following week. During the period of relatively high barometer, temperature falls quickly with a considerable augmentation in the precipitation. Northerly winds show a marked excess, a point of interest in connection with the rapid fall of temperature. There is a good deal of sunshine till about the 10th, when the polar current asserts itself. Gales become frequent about the 16th, when there is an increased tendency for snow. The most pronounced feature of the meteorology of the month is the great and rapid fall of pressure to a minimum on the 26th (see page 685), this being accompanied by an increase in equatorial winds, in consequence of which the autumnal fall of temperature is retarded.

December.

Pressure is below the mean in December during the first three weeks, temperature remaining steady till the 17th. The cause of this interruption in the regular autumnal fall of temperature is to be found in the increased prevalence first of S.E., then of S., and finally of westerly winds. Gales during this time are frequent, while snow is of uncommon occurrence. After the 17th temperature falls, S.W. winds blowing with diminished frequency. Snow now becomes frequent, while pressure is higher than during any time in the three months before or after. Calms are common at this time, pressure being high, conditions eminently favourable for the deposition of aqueous vapour on the dust particles and its consequent condensation into fog. The increase of S.E. winds at the close of the year is of interest in connection with the low temperature at the time.

Table I.

Showing the Mean Barometric Pressure of each Day of the Year at Edinburgh on the Mean of Fifty Years.

At 32° and Mean Sea-Level.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	29·858	29·704	29·831	29·782	29·955	29·991	29·920	29·888	29·887	29·760	29·797	29·836
2	·860	·727	·862	·764	·963	·949	·894	·878	·862	·829	·850	·922
3	·818	·767	·935	·775	·894	·918	·848	·828	·855	·836	·814	·814
4	·820	·877	·904	·781	·930	·916	·855	·834	·917	·913	·795	·813
5	·748	·861	·905	·801	·941	·903	·858	·849	·906	·906	·799	·757
6	·834	·863	·832	·850	·914	·900	·845	·824	·885	·867	·863	·747
7	·850	·793	·801	·880	·884	·902	·822	·804	·855	·766	·875	·769
8	·790	·780	·810	·867	·879	·889	·822	·789	·912	·804	·881	·835
9	·842	·845	·817	·926	·900	·880	·850	·830	·840	·768	·905	·846
10	·832	·792	·817	·947	·961	·884	·905	·841	·858	·764	·858	·865
11	·850	·829	·803	·931	·958	·910	·904	·841	·912	·758	·855	·841
12	·878	·876	·801	·917	·937	·909	·912	·866	·951	·831	·892	·889
13	·852	·900	·846	·901	30·013	·912	·903	·833	·972	·849	·864	·803
14	·842	·874	·843	·914	29·986	·942	·876	·850	·940	·817	·839	·825
15	·835	·875	·825	·930	·946	·935	·932	·853	·924	·789	·842	·812
16	·846	·868	·864	·900	·905	·992	·928	·863	·934	·750	·830	·782
17	·835	·885	·865	·914	·856	·984	·888	·836	·956	·746	·849	·835
18	·771	·881	·889	·945	·815	·987	·852	·890	·934	·813	·902	·749
19	·764	·887	·899	·900	·865	·972	·841	·882	·917	·771	·842	·729
20	·761	·871	·830	·859	·888	·979	·847	·879	·890	·740	·841	·753
21	·828	·914	·878	·877	·954	·937	·852	·873	·891	·781	·831	·840
22	·807	·898	·931	·869	·965	·900	·832	·854	·842	·750	·655	·815
23	·766	·921	·913	·878	·946	·905	·836	·855	·868	·718	·695	·908
24	·741	·894	·837	·917	·942	·924	·838	·874	·879	·707	·716	·879
25	·735	·889	·828	·895	·907	·915	·820	·874	·870	·764	·637	·901
26	·736	·826	·749	·923	·923	·930	·870	·828	·874	·786	·628	·927
27	·764	·820	·789	·930	·904	·936	·891	·866	·803	·759	·706	·948
28	·713	·852	·821	·912	·918	·929	·918	·861	·784	·786	·759	·918
29	·745	...	·815	·961	·952	·941	·913	·869	·772	·801	·734	·829
30	·670	...	·790	·983	·956	·956	·889	·871	·813	·828	·791	·832
31	·679	...	·746	...	·984	...	·882	·880	...	·842	...	·855
Means	29·796	29·849	29·841	29·887	29·927	29·931	29·872	29·854	29·883	29·794	29·805	29·835

The Mean of the Twelve Monthly Values is 29·856 inches.

Table II.

Showing the Smoothed Difference from Mean of Year of Mean Barometric Pressure.

Thousandths of an Inch.

Day.	Jan.	Feb.	March.	April.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	**2**	*153*	*8*	*92*	**111**	**119**	**67**	**27**	**20**	*55*	*26*	*8*
2	*11*	*123*	**20**	*82*	**81**	**97**	**31**	**8**	**12**	*48*	*36*	**1**
3	*23*	*66*	**44**	*83*	**73**	**72**	**10**	*9*	**22**	**3**	*36*	*6*
4	*61*	*21*	**59**	*70*	**66**	**50**	*2*	*19*	**37**	**29**	*53*	*61*
5	*55*	**11**	**24**	*45*	**72**	**50**	*3*	*20*	**47**	**39**	*37*	*84*
6	*45*	*17*	*10*	*12*	**57**	**46**	*14*	*30*	**26**	*10*	*10*	*98*
7	*31*	*44*	*42*	**10**	**36**	**41**	*26*	*50*	**28**	*44*	**17**	*72*
8	*29*	*50*	*47*	**35**	**32**	**34**	*25*	*48*	**13**	*77*	**31**	*39*
9	*35*	*50*	*41*	**57**	**57**	**28**	**3**	*36*	**14**	*77*	**25**	*7*
10	*15*	*34*	*44*	**75**	**84**	**35**	**30**	*19*	**14**	*93*	**17**	*5*
11	*3*	*24*	*49*	**72**	**96**	**45**	**51**	*7*	**51**	*72*	**12**	**9**
12	**4**	**12**	*39*	**57**	**113**	**54**	**50**	*13*	**89**	*43*	**14**	*12*
13	**1**	**27**	*26*	**55**	**123**	**65**	**41**	*6*	**98**	*24*	**9**	*17*
14	*13*	**27**	*18*	**59**	**126**	**74**	**48**	*11*	**89**	*38*	*8*	*43*
15	*15*	**16**	*12*	**59**	**90**	**100**	**56**	*1*	**77**	*71*	*19*	*50*
16	*17*	**20**	*5*	**59**	**46**	**114**	**60**	*5*	**82**	*94*	*16*	*46*
17	*39*	**22**	**17**	**64**	**3**	**132**	**33**	**7**	**85**	*86*	**4**	*67*
18	*66*	**28**	**28**	**64**	*10*	**125**	**4**	**13**	**80**	*79*	**8**	*85*
19	*91*	**24**	**17**	**45**	*0*	**123**	*11*	**28**	**58**	*81*	**6**	*112*
20	*72*	**35**	**13**	**23**	**47**	**107**	*9*	**22**	**43**	*92*	*18*	*82*
21	*57*	**38**	**24**	**12**	**80**	**83**	*12*	**13**	**18**	*99*	*80*	*53*
22	*56*	**55**	**51**	**19**	**99**	**58**	*16*	**5**	**11**	*106*	*129*	*2*
23	*85*	**48**	**38**	**32**	**95**	**53**	*21*	**5**	**7**	*131*	*167*	**11**
24	*109*	**45**	**3**	**44**	**76**	**59**	*25*	**12**	**16**	*126*	*173*	**40**
25	*119*	**14**	*51*	**56**	**68**	**67**	*13*	**3**	**18**	*104*	*196*	**46**
26	*111*	*11*	*67*	**60**	**55**	**71**	**4**	**3**	*7*	*86*	*199*	**69**
27	*118*	*23*	*69*	**66**	**59**	**76**	**27**	*4*	*36*	*79*	*158*	**75**
28	*115*	*22*	*48*	**78**	**69**	**79**	**51**	**9**	*70*	*74*	*123*	**42**
29	*150*	...	*47*	**96**	**86**	**86**	**51**	**11**	*66*	*51*	*95*	**4**
30	*161*	...	*72*	**110**	**108**	**83**	**39**	**17**	*74*	*32*	*69*	*17*
31	*175*	...	*83*	...	**122**	...	**30**	**23**	...	*34*	...	*8*

Note.—The heavy type indicates an excess, and the italic type a defect.

TABLE III.

Showing the Mean Temperature of the Air at Edinburgh on each Day of the Year during Fifty Years.

Mean of Max. and Min.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	38·16	39·15	38·71	43·18	48·00	54·09	57·48	57·82	55·76	50·91	44·75	38·83
2	37·24	38·44	39·31	43·60	46·84	53·91	57·86	57·95	57·06	50·03	44·27	39·73
3	36·90	39·06	40·15	44·16	47·31	53·40	57·77	57·73	56·08	49·48	44·55	39·82
4	36·96	39·93	40·03	43·69	46·69	53·87	57·48	58·05	55·47	49·25	44·29	40·59
5	36·99	40·03	40·45	44·42	47·11	53·94	57·57	58·23	55·93	49·34	43·96	40·88
6	36·28	38·89	40·58	43·91	47·56	54·54	57·70	58·60	56·04	49·84	43·22	40·12
7	36·42	39·33	40·60	43·59	48·79	54·38	57·90	58·96	55·88	49·30	43·16	39·91
8	36·70	38·20	40·43	44·06	48·25	54·12	58·32	58·84	55·29	49·42	43·62	39·16
9	36·52	36·75	39·35	43·41	47·67	54·36	57·59	58·02	55·42	48·67	42·74	39·65
10	36·91	37·70	39·42	43·53	47·90	54·06	57·62	57·85	55·22	49·19	41·46	40·26
11	37·07	38·50	39·57	43·42	48·05	54·06	57·90	58·10	55·09	48·64	41·38	39·84
12	37·21	38·34	39·40	43·25	48·73	54·19	58·49	59·17	54·85	47·98	40·60	39·25
13	37·93	38·37	39·66	43·66	49·63	55·48	58·99	58·76	55·44	47·82	41·37	39·25
14	38·28	39·52	39·99	43·36	49·43	55·65	58·99	58·81	55·32	48·22	41·40	39·28
15	37·80	39·67	40·39	44·64	49·09	55·67	59·11	58·48	54·44	48·13	41·68	39·24
16	38·11	39·52	40·15	45·29	49·88	55·53	58·21	58·06	54·56	47·23	40·86	40·02
17	37·66	39·65	40·86	44·73	50·02	55·68	58·19	57·57	53·90	47·47	40·98	39·31
18	38·84	40·12	41·90	45·67	50·29	56·08	58·35	57·82	53·67	47·40	40·65	39·25
19	38·80	39·48	41·02	46·40	50·34	56·49	58·62	57·58	52·83	46·91	41·84	38·70
20	37·42	39·08	40·58	46·76	50·99	56·98	58·32	57·22	53·11	46·47	41·32	38·43
21	36·31	39·82	40·01	46·76	50·86	57·97	59·11	57·52	51·91	45·71	41·38	37·98
22	36·99	39·57	40·91	45·52	51·02	57·26	58·39	56·68	51·52	45·83	40·88	37·71
23	37·86	40·07	41·51	44·88	52·07	56·55	58·34	56·79	52·09	45·93	39·52	36·99
24	38·48	39·70	41·92	45·34	52·72	56·24	58·29	56·59	52·56	45·31	40·01	37·03
25	38·66	39·33	41·73	46·03	52·18	56·51	57·85	57·13	52·39	44·10	40·15	37·76
26	38·57	38·80	40·98	46·11	51·99	56·90	58·01	56·90	52·15	43·92	40·03	37·82
27	38·99	38·35	41·10	45·99	52·33	58·14	57·51	56·66	52·60	44·76	39·83	37·05
28	39·11	38·69	41·34	46·16	51·85	58·29	57·99	56·54	51·64	44·60	40·00	37·60
29	38·49	(39·18)	42·23	46·64	52·49	58·14	57·70	56·25	51·31	44·08	40·21	38·49
30	39·32	...	42·44	46·80	53·20	57·32	57·87	56·06	51·13	44·11	39·33	37·96
31	39·21	...	43·36	...	53·00	...	57·72	55·82	...	44·24	...	37·85
Means	37·75	39·07	40·65	44·83	49·88	55·66	58·10	57·63	54·02	47·24	41·65	38·90

The Mean of the Twelve Monthly Values is 47°·11.

Table IV.

Showing the Smoothed Difference from Mean of Year of the Mean Temperature Deduced from Fifty Years' Observation.

Day.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	*9·4*	*8·2*	*8·2*	*3·7*	**0·1**	**6·6**	**10·4**	**10·7**	**9·1**	**3·6**	*2·7*	*7·8*
2	*9·7*	*8·2*	*7·7*	*3·5*	**0·3**	**6·7**	**10·6**	**10·7**	**9·2**	**3·0**	*2·6*	*7·6*
3	*10·1*	*8·0*	*7·3*	*3·3*	*0·1*	**6·6**	**10·6**	**10·9**	**9·1**	**2·5**	*2·7*	*7·1*
4	*10·2*	*7·4*	*6·9*	*3·0*	*0·1*	**6·6**	**10·5**	**10·9**	**8·7**	**2·2**	*2·8*	*6·7*
5	*10·4*	*7·5*	*6·8*	*3·1*	*0·0*	**7·0**	**10·5**	**11·2**	**8·7**	**2·4**	*3·3*	*6·6*
6	*10·5*	*7·7*	*6·6*	*3·1*	**0·7**	**7·2**	**10·6**	**11·5**	**8·8**	**2·4**	*3·7*	*6·8*
7	*10·6*	*8·3*	*6·6*	*3·2*	**1·1**	**7·2**	**10·9**	**11·7**	**8·6**	**2·4**	*3·8*	*7·4*
8	*10·6*	*9·0*	*7·0*	*3·4*	**1·1**	**7·2**	**10·8**	**11·2**	**8·4**	**2·0**	*3·9*	*7·5*
9	*10·4*	*9·6*	*7·4*	*3·4*	**0·8**	**7·1**	**10·7**	**11·1**	**8·2**	**2·0**	*4·5*	*7·4*
10	*10·3*	*9·5*	*7·7*	*3·7*	**0·8**	**7·0**	**10·6**	**10·9**	**8·1**	**1·7**	*5·2*	*7·2*
11	*10·0*	*8·9*	*7·6*	*3·7*	**1·1**	**7·0**	**10·9**	**11·3**	**7·9**	**1·5**	*6·0*	*7·3*
12	*9·7*	*8·7*	*7·6*	*3·7*	**1·7**	**7·5**	**11·4**	**11·6**	**7·7**	**1·0**	*6·0*	*7·7*
13	*9·3*	*8·4*	*7·4*	*3·7*	**2·1**	**8·0**	**11·7**	**11·8**	**7·8**	**0·9**	*6·0*	*7·9*
14	*9·1*	*7·9*	*7·1*	*3·2*	**2·3**	**8·5**	**11·9**	**11·6**	**7·6**	**0·9**	*5·6*	*7·9*
15	*9·0*	*7·5*	*6·9*	*2·7*	**2·4**	**8·5**	**11·7**	**11·3**	**7·7**	**0·7**	*5·8*	*7·6*
16	*9·2*	*7·5*	*6·6*	*2·2*	**2·6**	**8·5**	**11·4**	**10·9**	**7·2**	**0·5**	*5·9*	*7·6*
17	*8·9*	*7·3*	*6·1*	*1·9*	**3·0**	**8·6**	**11·1**	**10·7**	**6·9**	**0·3**	*6·3*	*7·6*
18	*8·7*	*7·4*	*5·8*	*1·5*	**3·1**	**9·0**	**11·3**	**10·5**	**6·4**	**0·1**	*5·9*	*8·0*
19	*8·8*	*7·5*	*5·9*	*0·8*	**3·4**	**9·4**	**11·3**	**10·4**	**6·1**	*0·2*	*5·8*	*8·4*
20	*9·6*	*7·7*	*6·6*	*0·5*	**3·6**	**10·0**	**11·6**	**10·3**	**5·5**	*0·7*	*5·6*	*8·7*
21	*10·2*	*7·6*	*6·6*	*0·8*	**3·8**	**10·3**	**11·5**	**10·0**	**5·1**	*1·1*	*5·9*	*9·1*
22	*10·1*	*7·3*	*6·3*	*1·4*	**4·2**	**10·2**	**11·5**	**9·9**	**4·7**	*1·3*	*6·5*	*9·5*
23	*9·3*	*7·3*	*5·7*	*1·9*	**4·8**	**9·9**	**11·2**	**9·6**	**4·9**	*1·4*	*7·0*	*9·9*
24	*8·8*	*7·4*	*5·4*	*1·7*	**5·2**	**9·3**	**11·1**	**9·7**	**5·2**	*2·0*	*7·2*	*9·8*
25	*8·5*	*7·8*	*5·6*	*1·3*	**5·2**	**9·4**	**10·9**	**9·8**	**5·3**	*2·7*	*7·0*	*9·6*
26	*8·4*	*8·3*	*5·8*	*1·1*	**5·0**	**10·1**	**10·7**	**9·8**	**5·3**	*2·8*	*7·0*	*9·6*
27	*8·2*	*8·5*	*6·0*	*1·0*	**4·9**	**10·7**	**10·7**	**9·6**	**5·0**	*2·7*	*7·2*	*9·6*
28	*8·2*	*8·5*	*5·6*	*0·8*	**5·1**	**11·1**	**10·6**	**9·4**	**4·7**	*2·6*	*7·1*	*9·4*
29	*8·1*	...	*5·1*	*0·6*	**5·4**	**10·8**	**10·7**	**9·2**	**4·2**	*2·8*	*7·3*	*9·1*
30	*8·1*	...	*4·4*	*0·0*	**5·8**	**10·5**	**10·7**	**8·9**	**4·0**	*3·0*	*7·7*	*9·0*
31	*7·9*	...	*4·1*	...	**6·3**	...	...	**8·8**	...	*2·7*	...	*9·1*

Note.—The heavy type indicates an excess, and the italic type a defect.

Table V.

Showing the Mean Temperature of the Air on each Day of the Year at Edinburgh during 100 *Years.*

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	37·36	38·16	39·02	42·62	48·07	53·94	57·29	58·24	55·77	50·71	44·60	39·22
2	36·34	37·79	38·86	43·34	47·16	54·06	57·65	58·32	56·46	50·34	44·54	39·56
3	36·24	37·61	39·72	43·19	47·50	53·65	57·70	58·37	55·83	50·16	44·38	39·29
4	36·87	37·80	39·70	43·32	47·40	53·96	57·79	58·72	55·66	49·76	43·42	39·86
5	36·60	38·06	39·29	43·72	47·80	53·74	58·17	58·78	55·70	49·17	43·51	39·86
6	36·27	38·14	39·36	43·70	47·85	54·31	57·99	58·65	55·64	49·70	42·95	39·43
7	36·12	38·70	39·43	43·88	48·58	54·55	57·85	58·77	55·51	49·77	42·80	39·70
8	35·86	38·47	39·58	44·17	48·58	54·37	58·30	59·23	54·86	49·45	42·59	39·22
9	35·91	38·00	39·46	43·58	47·96	54·48	57·92	58·45	55·00	49·42	42·29	39·60
10	36·02	38·23	39·43	43·68	47·92	54·41	57·94	58·30	54·91	48·95	41·69	39·36
11	35·92	38·37	39·56	43·46	48·40	54·73	58·46	58·58	54·86	48·59	41·94	39·47
12	36·18	38·10	39·68	43·96	48·78	55·08	58·58	58·98	54·47	47·81	41·27	39·34
13	37·20	38·18	40·13	43·94	49·22	55·88	58·88	58·33	54·64	47·80	41·80	39·50
14	36·67	38·69	40·14	44·31	48·86	55·86	58·98	58·20	54·74	48·33	41·41	39·25
15	35·92	38·92	40·40	45·07	49·44	56·00	59·20	58·27	54·45	48·18	41·24	39·30
16	36·86	39·10	40·50	45·02	50·38	56·21	59·06	57·75	54·80	47·74	40·37	39·82
17	36·63	38·71	40·83	44·66	50·61	56·36	58·80	57·72	54·27	47·78	40·89	39·32
18	37·58	38·61	41·55	44·88	50·56	56·33	58·77	58·04	53·68	47·10	39·90	39·22
19	37·82	38·32	41·20	45·64	50·53	56·20	58·63	58·00	53·30	47·18	40·63	38·73
20	37·03	38·42	41·31	46·30	50·88	56·59	58·68	57·51	52·67	47·00	40·61	38·30
21	36·34	38·60	41·10	46·28	51·09	57·06	58·74	57·45	52·12	46·31	40·67	37·99
22	36·57	38·70	41·20	45·97	51·26	56·71	58·48	56·57	51·51	46·28	40·30	37·86
23	37·24	39·52	41·16	45·55	52·10	56·80	58·61	57·28	51·67	46·06	39·72	37·06
24	37·87	39·48	41·37	45·42	52·70	56·74	58·88	57·10	52·55	45·90	39·62	37·06
25	37·62	39·22	41·36	46·15	52·21	56·78	58·48	57·00	52·50	45·07	39·06	37·41
26	37·84	38·66	40·91	46·46	52·16	56·89	58·64	56·62	52·40	44·48	39·92	37·06
27	37·62	38·70	41·85	46·46	52·72	57·76	58·52	56·72	52·23	44·93	39·35	36·42
28	37·74	38·87	41·86	47·00	52·36	58·06	58·62	56·55	51·53	44·31	39·54	36·65
29	37·34	(39·00)	42·12	47·25	52·91	58·18	58·18	56·66	51·27	43·83	39·86	37·22
30	38·38	...	41·96	47·47	53·10	57·57	58·26	56·52	51·08	44·34	39·86	37·45
31	38·04	...	43·02	...	53·36	...	58·19	56·21	...	44·24	...	37·20
Means	36·90	38·50	40·55	44·88	50·08	55·78	58·39	57·80	53·87	47·44	41·96	38·60

The Mean of the Twelve Monthly Values is 47°·06.

Table VI.

Showing the Smoothed Difference from Mean of Year of the Mean Temperature deduced from 100 Years' Observation.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	*10·1*	*9·1*	*8·1*	*4·1*	**0·5**	**6·7**	**10·4**	**11·2**	**9·1**	**3·6**	*2·6*	*7·5*
2	*10·8*	*9·2*	*7·9*	*4·0*	**0·5**	**6·8**	**10·5**	**11·3**	**9·0**	**3·3**	*2·6*	*7·7*
3	*10·9*	*9·3*	*7·6*	*3·8*	**0·3**	**6·8**	**10·6**	**11·4**	**8·9**	**3·0**	*2·9*	*7·5*
4	*10·8*	*9·2*	*7·5*	*3·7*	**0·5**	**6·7**	**10·8**	**11·6**	**8·7**	**2·6**	*3·3*	*7·4*
5	*10·5*	*9·1*	*7·6*	*3·5*	**0·6**	**6·9**	**10·9**	**11·7**	**8·6**	**2·5**	*3·8*	*7·3*
6	*10·7*	*8·8*	*7·7*	*3·3*	**1·0**	**7·1**	**10·9**	**11·7**	**8·6**	**2·5**	*4·0*	*7·4*
7	*11·0*	*8·6*	*7·6*	*3·1*	**1·3**	**7·3**	**11·0**	**11·8**	**8·3**	**2·6**	*4·3*	*7·6*
8	*11·1*	*8·7*	*7·6*	*3·2*	**1·3**	**7·4**	**11·0**	**11·8**	**8·1**	**2·5**	*4·5*	*7·6*
9	*11·1*	*8·8*	*7·6*	*3·2*	**1·1**	**7·4**	**11·0**	**11·6**	**7·9**	**2·2**	*4·9*	*7·7*
10	*11·1*	*8·9*	*7·6*	*3·5*	**1·0**	**7·5**	**11·0**	**11·4**	**7·9**	**1·9**	*5·1*	*7·6*
11	*11·0*	*8·8*	*7·5*	*3·4*	**1·3**	**7·7**	**11·3**	**11·6**	**7·7**	**1·4**	*5·4*	*7·7*
12	*10·6*	*8·8*	*7·3*	*3·3*	**1·7**	**8·2**	**11·6**	**11·6**	**7·6**	**1·0**	*5·4*	*7·6*
13	*10·4*	*8·7*	*7·1*	*3·0*	**1·9**	**8·5**	**11·8**	**11·4**	**7·6**	**0·9**	*5·6*	*7·7*
14	*10·5*	*8·5*	*6·8*	*2·6*	**2·1**	**8·9**	**12·0**	**11·2**	**7·5**	**1·0**	*5·6*	*7·7*
15	*10·6*	*8·2*	*6·7*	*2·3*	**2·5**	**9·0**	**12·0**	**11·0**	**7·6**	**1·0**	*6·1*	*7·6*
16	*10·6*	*8·2*	*6·5*	*2·1*	**3·1**	**9·1**	**12·0**	**10·9**	**7·4**	**0·8**	*6·2*	*7·6*
17	*10·0*	*8·2*	*6·1*	*2·2*	**3·5**	**9·2**	**11·8**	**10·8**	**7·2**	**0·5**	*6·7*	*7·6*
18	*9·7*	*8·5*	*5·9*	*2·0*	**3·5**	**9·2**	**11·7**	**10·9**	**6·7**	**0·3**	*6·6*	*8·0*
19	*9·6*	*8·6*	*5·7*	*1·5*	**3·6**	**9·3**	**11·6**	**10·8**	**6·2**	*0·0*	*6·7*	*8·3*
20	*10·0*	*8·6*	*5·9*	*1·0*	**3·8**	**9·6**	**11·6**	**10·6**	**5·6**	*0·2*	*6·4*	*8·7*
21	*10·4*	*8·5*	*5·9*	*0·9*	**4·0**	**9·7**	**11·6**	**10·1**	**5·0**	*0·5*	*6·5*	*9·0*
22	*10·3*	*8·1*	*5·9*	*1·1*	**4·3**	**9·8**	**11·5**	**10·0**	**4·7**	*0·8*	*6·8*	*9·4*
23	*9·8*	*7·8*	*5·8*	*1·4*	**5·0**	**9·7**	**11·6**	**9·9**	**4·8**	*1·0*	*7·2*	*9·7*
24	*9·5*	*7·7*	*5·8*	*1·4*	**5·3**	**9·7**	**11·6**	**10·1**	**5·2**	*1·4*	*7·6*	*9·9*
25	*9·3*	*7·9*	*5·8*	*1·0*	**5·3**	**9·7**	**11·6**	**9·8**	**5·4**	*1·9*	*7·5*	*9·9*
26	*9·4*	*8·2*	*5·7*	*0·7*	**5·3**	**10·1**	**11·5**	**9·7**	**5·3**	*2·2*	*7·6*	*10·1*
27	*9·3*	*8·3*	*5·5*	*0·4*	**5·4**	**10·5**	**11·5**	**9·6**	**5·0**	*2·5*	*7·5*	*10·3*
28	*9·5*	*8·2*	*5·1*	*0·2*	**5·6**	**10·9**	**11·4**	**9·6**	**4·6**	*2·6*	*7·5*	*10·0*
29	*9·2*	...	*5·1*	**0·2**	**5·7**	**10·9**	**11·3**	**9·5**	**4·2**	*2·9*	*7·3*	*10·0*
30	*9·1*	...	*4·7*	**0·5**	**6·1**	**10·6**	**11·1**	**9·4**	**3·9**	*2·9*	*7·4*	*9·8*
31	*8·9*	...	*4·5*	...	**6·4**	...	**11·2**	**9·1**	...	*2·7*	...	*9·7*

Note.—The heavy type indicates an excess, and the italic type a defect.

Table VII.

Showing the Mean Maximum Temperature of the Air at Edinburgh on each Day of the Year during Fifty Years.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	42·66	44·28	44·00	50·48	56·02	62·42	65·12	65·76	63·28	57·56	49·52	44·40
2	41·68	43·42	45·30	50·74	54·84	61·66	65·66	65·64	63·82	56·52	49·68	45·80
3	41·72	44·26	45·40	51·16	55·12	60·82	65·20	64·84	62·86	55·80	50·02	44·82
4	41·76	45·06	45·52	50·84	54·44	61·48	64·80	65·66	62·64	55·30	49·80	45·80
5	41·64	45·30	46·58	50·98	54·64	61·88	65·20	65·90	63·52	55·58	49·62	45·82
6	41·36	43·88	46·54	50·82	54·98	62·10	64·98	65·90	63·34	56·26	48·52	44·86
7	41·34	44·62	46·78	50·24	55·72	61·90	65·36	65·84	63·14	55·26	48·86	44·04
8	41·10	43·62	46·84	50·56	56·20	62·24	65·96	65·42	63·18	55·42	48·34	44·38
9	40·98	41·74	45·48	50·48	55·38	62·08	64·98	65·30	63·02	54·72	47·72	44·44
10	41·66	42·46	45·76	50·38	55·76	61·74	65·48	65·40	62·48	55·26	46·48	45·18
11	42·18	43·72	45·76	50·86	55·28	62·22	65·24	65·44	62·70	54·72	46·36	44·68
12	41·98	43·94	45·48	50·58	56·28	61·98	66·10	66·60	62·38	54·22	45·88	43·96
13	42·90	43·56	45·78	50·66	57·32	63·32	66·60	65·84	62·68	53·60	46·50	43·74
14	43·00	44·96	46·50	50·18	56·94	64·10	66·32	66·64	63·10	53·60	46·72	44·46
15	42·96	45·22	46·50	51·36	56·42	63·60	66·54	65·98	61·22	54·08	46·50	43·88
16	43·16	44·44	46·02	52·68	57·64	63·86	66·36	65·04	61·38	52·80	46·34	44·54
17	42·94	44·94	47·14	52·32	57·84	63·48	66·34	64·42	61·06	53·04	46·36	43·82
18	43·66	45·34	48·04	52·84	57·54	64·06	65·90	65·04	60·48	52·36	46·04	44·28
19	43·56	44·72	47·42	53·60	57·82	64·98	66·08	64·42	59·90	52·30	47·18	43·44
20	42·68	44·32	46·46	54·34	59·04	65·50	66·26	64·76	59·68	52·32	45·66	42·62
21	41·68	44·50	46·76	53·98	58·94	66·06	66·76	64·08	58·32	51·60	46·66	42·94
22	41·98	45·14	47·72	52·74	59·86	65·50	65·66	64·04	58·36	51·74	45·52	42·52
23	43·02	45·38	47·98	51·56	60·18	64·70	66·08	64·08	58·60	51·36	44·80	41·78
24	43·46	44·82	48·50	52·68	60·86	63·84	65·70	64·08	58·58	50·58	45·52	41·86
25	44·08	44·88	48·36	53·56	59·56	63·50	64·82	64·86	58·90	50·22	45·08	42·62
26	44·16	44·44	47·24	53·88	59·84	64·96	65·40	64·12	58·52	50·34	45·20	42·70
27	44·16	43·84	47·18	53·76	60·04	65·64	64·88	63·80	59·28	50·32	44·46	42·02
28	43·86	43·98	47·58	53·86	59·80	66·04	65·68	64·30	58·30	50·38	44·94	42·44
29	43·60	(43·55)	48·98	54·74	60·30	65·92	65·08	63·72	57·84	49·88	45·24	43·14
30	44·58	...	49·42	54·42	61·24	65·12	65·20	63·58	57·42	49·52	44·44	42·76
31	43·60	...	50·66	...	61·52	...	65·08	63·14	...	49·52	...	42·92
Means	42·68	44·31	46·89	52·04	57·65	63·55	65·64	64·96	61·00	53·10	46·80	43·76

The Mean of the Twelve Monthly Values is 53°·53.

TABLE VIII.

Showing the Smoothed Difference from Mean of Year of the Mean Maximum Temperature deduced from Fifty Years' Observation.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	*11·1*	*9·8*	*9·1*	*3·0*	**1·6**	**8·3**	**11·8**	**12·0**	**9·9**	**3·6**	*4·0*	*8·7*
2	*11·5*	*9·5*	*8·6*	*2·7*	**1·8**	**8·1**	**11·8**	**12·2**	**9·8**	**3·1**	*3·8*	*8·5*
3	*11·8*	*9·3*	*8·1*	*2·6*	**1·3**	**7·8**	**11·7**	**11·8**	**9·6**	**2·3**	*3·7*	*8·1*
4	*11·8*	*8·7*	*7·7*	*2·5*	**1·2**	**7·9**	**11·5**	**11·9**	**9·5**	**2·0**	*3·7*	*8·0*
5	*11·9*	*8·8*	*7·3*	*2·6*	**1·2**	**8·3**	**11·4**	**12·3**	**9·6**	**2·2**	*4·2*	*8·0*
6	*12·1*	*8·9*	*6·9*	*2·9*	**1·6**	**8·4**	**11·7**	**12·4**	**9·8**	**2·2**	*4·2*	*8·6*
7	*12·3*	*9·5*	*6·8*	*3·0*	**2·1**	**8·6**	**11·9**	**12·2**	**9·7**	**2·1**	*5·0*	*9·1*
8	*12·4*	*10·2*	*7·2*	*3·1*	**2·2**	**8·5**	**11·9**	**12·0**	**9·6**	**1·6**	*5·2*	*9·2*
9	*12·3*	*10·9*	*7·5*	*3·1*	**2·3**	**8·5**	**11·9**	**11·8**	**9·4**	**1·6**	*6·0*	*8·9*
10	*11·9*	*10·9*	*7·9*	*3·0*	**1·9**	**8·5**	**11·7**	**11·9**	**9·2**	**1·4**	*6·7*	*8·8*
11	*11·6*	*10·2*	*7·9*	*2·9*	**2·2**	**8·4**	**12·1**	**12·3**	**9·0**	**1·2**	*7·3*	*8·9*
12	*11·2*	*9·8*	*7·9*	*2·8*	**2·8**	**9·0**	**12·5**	**12·4**	**9·0**	**0·6**	*7·3*	*9·4*
13	*10·9*	*9·4*	*7·6*	*3·1*	**3·3**	**9·7**	**12·8**	**12·8**	**9·2**	**0·3**	*7·2*	*9·5*
14	*10·6*	*8·9*	*7·3*	*2·8*	**3·4**	**10·1**	**12·9**	**12·7**	**8·8**	**0·2**	*6·9*	*9·5*
15	*10·5*	*8·7*	*7·2*	*2·1*	**3·5**	**10·3**	**12·9**	**12·4**	**8·4**	*0·0*	*7·0*	*9·2*
16	*10·5*	*8·7*	*7·0*	*1·4*	**3·8**	**10·1**	**12·9**	**11·6**	**7·7**	*0·2*	*7·1*	*9·5*
17	*10·3*	*8·6*	*6·5*	*0·9*	**4·1**	**10·1**	**12·7**	**11·3**	**7·4**	*0·8*	*7·3*	*9·3*
18	*10·1*	*8·5*	*6·0*	*0·6*	**4·2**	**10·6**	**12·6**	**11·1**	**6·9**	*1·0*	*7·0*	*9·7*
19	*10·2*	*8·7*	*6·2*	0·1	**4·6**	**11·3**	**12·5**	**11·2**	**6·5**	*1·2*	*7·2*	*10·1*
20	*10·9*	*9·0*	*6·7*	0·4	**5·1**	**12·0**	**12·8**	**10·9**	**5·8**	*1·5*	*7·0*	*10·5*
21	*11·4*	*8·9*	*6·6*	0·2	**5·7**	**12·2**	**12·7**	**10·8**	**5·3**	*1·6*	*7·6*	*10·8*
22	*11·3*	*8·5*	*6·0*	*0·8*	**6·1**	**11·9**	**12·6**	**10·5**	**4·9**	*2·0*	*7·9*	*11·1*
23	*10·7*	*8·4*	*5·5*	*1·2*	**6·8**	**11·1**	**12·3**	**10·5**	**5·0**	*2·3*	*8·2*	*11·5*
24	*10·0*	*8·5*	*5·2*	*0·9*	**6·7**	**10·5**	**12·0**	**10·8**	**5·2**	*2·8*	*8·4*	*11·4*
25	*10·0*	*8·8*	*5·5*	*0·2*	**6·6**	**10·6**	**11·8**	**10·8**	**5·1**	*3·2*	*8·3*	*11·1*
26	*9·4*	*9·1*	*5·9*	0·2	**6·3**	**11·2**	**11·5**	**10·7**	**5·4**	*3·2*	*8·6*	*11·1*
27	*9·5*	*9·4*	*6·2*	0·3	**6·4**	**12·0**	**11·8**	**10·5**	**5·2**	*3·2*	*8·7*	*11·1*
28	*9·7*	*9·6*	*5·6*	0·6	**6·5**	**12·3**	**11·7**	**10·4**	**4·9**	*3·3*	*8·6*	*11·0*
29	*9·5*	...	*4·9*	0·8	**6·9**	**12·2**	**11·8**	**10·3**	**4·3**	*3·6*	*8·7*	*10·7*
30	*9·6*	...	*3·8*	1·5	**7·5**	**11·9**	**11·6**	**9·9**	**4·1**	*3·9*	*8·8*	*10·6*
31	*9·4*	...	*3·3*	...	**8·2**	...	**11·8**	**9·8**	...	*4·0*	...	*10·8*

NOTE.—The heavy type **indicates an excess, and** the italic type a defect.

TABLE IX.

Showing the Mean Minimum Temperature of the Air at Edinburgh on each Day of the Year during Fifty Years.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	33·66	34·02	33·42	35·90	39·98	45·76	49·84	49·88	48·24	44·26	39·98	34·26
2	32·80	33·46	33·32	36·46	38·84	46·16	50·06	50·26	50·30	43·54	38·86	33·66
3	32·08	33·86	34·90	37·16	39·50	45·98	50·34	50·62	49·30	43·16	39·08	34·82
4	32·16	34·80	34·54	36·54	38·94	46·26	50·16	50·44	48·30	43·20	38·78	35·38
5	32·34	34·76	34·32	37·86	39·58	46·00	49·94	50·56	48·34	43·10	38·30	35·94
6	31·20	33·90	34·62	37·00	40·14	46·98	50·42	51·30	48·74	43·40	37·92	35·38
7	31·50	34·04	34·42	36·94	40·86	46·86	50·44	51·08	48·62	43·34	37·46	35·78
8	32·30	32·78	34·02	37·56	40·28	46·00	50·68	52·26	47·40	43·42	38·90	33·94
9	32·06	31·76	33·22	36·34	39·96	46·64	50·20	50·76	47·82	42·62	37·76	34·86
10	32·16	32·94	33·08	36·68	40·04	46·38	49·76	50·30	47·96	43·12	36·44	35·34
11	31·96	33·28	33·38	35·98	40·92	45·90	50·56	50·76	47·48	42·56	36·40	35·00
12	32·44	32·74	33·32	35·92	41·18	46·40	50·88	51·74	47·32	41·74	35·32	34·54
13	32·96	33·18	33·54	36·66	41·94	47·64	51·38	51·68	48·20	42·04	36·24	34·76
14	33·56	34·14	33·48	36·54	41·92	47·20	51·66	50·98	47·54	42·84	36·08	34·10
15	32·64	34·12	34·28	37·92	41·76	47·74	51·68	50·98	47·66	42·18	36·86	34·61
16	33·06	34·60	34·28	37·90	42·12	47·20	50·06	51·08	47·74	41·66	35·38	35·50
17	32·38	34·36	34·56	37·14	42·20	47·88	50·04	50·72	46·74	41·90	35·60	34·80
18	34·02	34·90	35·76	38·50	43·04	48·10	50·80	50·60	46·86	41·44	35·26	34·22
19	34·04	34·24	34·62	39·20	42·86	48·00	51·16	50·74	45·76	41·52	36·50	33·96
20	32·16	33·84	34·70	39·18	42·94	48·46	50·38	49·68	46·54	40·62	36·98	34·24
21	30·94	34·14	33·26	39·54	42·78	49·88	51·46	50·96	45·50	39·82	36·10	33·02
22	32·00	34·00	34·10	38·30	43·18	49·02	51·12	49·32	44·68	39·92	36·24	32·90
23	32·70	34·76	35·04	38·20	43·96	48·40	50·60	49·50	45·58	40·50	34·30	32·20
24	33·50	34·58	35·34	38·00	44·58	48·64	50·88	49·10	46·54	40·04	34·50	32·20
25	33·24	33·78	35·10	38·50	44·80	49·52	50·88	49·40	45·88	39·98	35·22	32·90
26	32·98	33·16	34·72	38·34	44·14	48·84	50·62	49·68	45·78	37·50	34·86	32·94
27	33·82	32·86	35·02	38·22	44·62	50·64	50·14	49·52	45·92	39·20	35·20	32·08
28	34·36	33·40	35·10	38·46	43·90	50·54	50·30	48·78	44·98	38·82	35·06	32·76
29	33·38	(34·80)	35·48	38·54	44·68	50·36	50·32	48·78	44·78	38·28	35·18	33·84
30	34·06	...	35·46	39·18	45·16	49·52	50·54	48·54	44·84	38·70	34·22	33·16
31	34·82	...	36·06	...	44·48	...	50·36	48·50	...	38·96	...	32·78
Means	32·82	33·80	34·40	37·59	42·11	47·76	50·58	50·27	47·04	41·40	36·50	34·06

The Mean of the Twelve Monthly Values is 40°·69.

Table X.

Showing the Smoothed Difference from Mean of Year of the Mean Minimum Temperature deduced from Fifty Years' Observation.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	*7·6*	*6·6*	*7·3*	*4·6*	*1·4*	**4·8**	**9·1**	**9·5**	**8·3**	**3·5**	*1·4*	*6·6*
2	*7·8*	*6·9*	*7·1*	*4·2*	*1·3*	**5·3**	**9·4**	**9·6**	**8·6**	**3·0**	*1·4*	*6·4*
3	*8·3*	*6·7*	*6·8*	*4·0*	*1·6*	**5·3**	**9·5**	**9·8**	**8·6**	**2·6**	*1·8*	*6·1*
4	*8·5*	*6·2*	*6·4*	*3·5*	*1·4*	**5·4**	**9·5**	**9·9**	**8·0**	**2·5**	*2·0*	*5·8*
5	*8·8*	*6·2*	*6·2*	*3·6*	*1·2*	**5·7**	**9·5**	**10·1**	**7·8**	**2·5**	*2·4*	*5·1*
6	*9·0*	*6·5*	*6·2*	*3·4*	*0·5*	**5·9**	**9·6**	**10·3**	**7·9**	**2·6**	*2·8*	*5·0*
7	*9·0*	*7·1*	*6·3*	*3·5*	*0·2*	**5·9**	**9·8**	**10·9**	**7·6**	**2·7**	*2·6*	*5·7*
8	*8·7*	*7·8*	*6·8*	*3·7*	*0·3*	**5·8**	**9·8**	**10·7**	**7·3**	**2·1**	*2·6*	*5·8*
9	*8·5*	*8·2*	*7·2*	*3·8*	*0·6*	**5·6**	**9·6**	**10·4**	**7·0**	**2·4**	*3·0*	*6·0*
10	*8·6*	*8·0*	*7·5*	*4·4*	*0·4*	**5·6**	**9·5**	**9·9**	**7·1**	**2·1**	*3·8*	*5·6*
11	*8·5*	*7·7*	*7·4*	*4·5*	*0·0*	**5·5**	**9·7**	**10·2**	**6·9**	**1·8**	*4·6*	*5·7*
12	*8·2*	*7·6*	*7·3*	*4·5*	**0·7**	**6·0**	**10·2**	**10·7**	**7·0**	**1·4**	*4·7*	*5·9*
13	*7·7*	*7·3*	*7·2*	*4·3*	**1·0**	**6·4**	**10·6**	**10·8**	**7·0**	**1·5**	*4·8*	*6·2*
14	*7·6*	*6·9*	*6·9*	*3·7*	**1·2**	**6·8**	**10·9**	**10·5**	**7·1**	**1·7**	*4·3*	*6·2*
15	*7·6*	*6·4*	*6·7*	*3·2*	**1·2**	**6·7**	**10·4**	**10·3**	**7·0**	**1·5**	*4·6*	*5·9*
16	*8·0*	*6·3*	*6·3*	*3·0*	**1·3**	**6·9**	**9·9**	**10·2**	**7·0**	**1·2**	*4·7*	*5·7*
17	*7·5*	*6·1*	*5·8*	*2·8*	**1·8**	**7·0**	**9·6**	**10·1**	**6·4**	**1·0**	*5·3*	*5·8*
18	*7·2*	*6·2*	*5·7*	*2·4*	**2·0**	**7·3**	**10·0**	**10·0**	**5·8**	**0·9**	*4·9*	*6·4*
19	*7·2*	*6·4*	*5·7*	*1·7*	**2·3**	**7·5**	**10·1**	**9·7**	**5·7**	**0·5**	*4·4*	*6·5*
20	*8·3*	*6·6*	*6·5*	*1·4*	**2·2**	**8·1**	**10·3**	**9·8**	**5·2**	*0·0*	*4·2*	*7·0*
21	*9·0*	*6·7*	*6·7*	*1·7*	**2·3**	**8·4**	**10·3**	**9·3**	**4·9**	*0·6*	*4·2*	*7·3*
22	*8·8*	*6·4*	*6·6*	*2·0*	**2·6**	**8·4**	**10·4**	**9·2**	**4·2**	*0·6*	*5·1*	*8·0*
23	*8·0*	*6·2*	*5·9*	*2·5*	**3·2**	**8·0**	**10·2**	**8·6**	**4·9**	*0·5*	*5·7*	*8·3*
24	*7·5*	*6·3*	*5·5*	*2·5*	**3·8**	**8·2**	**10·1**	**8·6**	**5·3**	*0·5*	*6·0*	*8·3*
25	*7·5*	*6·8*	*5·6*	*2·4*	**3·8**	**8·3**	**10·1**	**8·7**	**5·4**	*1·5*	*5·8*	*8·0*
26	*7·3*	*7·4*	*5·7*	*2·3*	**3·8**	**9·0**	**9·9**	**8·8**	**5·2**	*1·8*	*5·6*	*8·0*
27	*7·0*	*7·5*	*5·7*	*2·3*	**3·5**	**9·3**	**9·7**	**8·6**	**4·9**	*2·2*	*5·6*	*8·1*
28	*6·8*	*7·5*	*5·5*	*2·3*	**3·7**	**9·8**	**9·6**	**8·3**	**4·5**	*1·9*	*5·5*	*7·8*
29	*6·8*	...	*5·3*	*2·0*	**3·9**	**9·4**	**9·7**	**8·0**	**4·2**	*2·1*	*5·9*	*7·4*
30	*6·6*	...	*5·0*	*1·5*	**4·1**	**9·2**	**9·7**	**7·9**	**3·9**	*2·0*	*6·1*	*7·4*
31	*6·4*	...	*4·9*	...	**4·4**	...	**9·6**	**7·7**	...	*1·5*	...	*7·5*

Note.—The heavy type indicates an excess and the italic type a defect.

TABLE XI.

Showing the Mean Daily Range of the Temperature of the Air at Edinburgh on each Day of the Year during Fifty Years.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	9·00	10·26	10·58	14·48	16·04	16·66	15·28	15·88	15·04	13·30	9·54	10·14
2	8·88	9·96	11·98	14·28	16·00	15·50	15·60	15·38	13·52	12·98	10·82	12·14
3	9·64	10·40	10·50	14·00	15·62	14·84	14·86	14·22	13·56	12·64	10·94	10·00
4	9·60	10·26	10·98	14·30	15·50	15·22	14·64	15·22	14·34	12·10	11·02	10·42
5	9·30	10·54	12·26	13·12	15·06	15·88	15·26	15·34	15·18	12·48	11·32	9·88
6	10·16	9·98	11·92	13·82	14·84	15·12	14·56	14·60	14·60	12·86	10·60	9·48
7	9·84	10·58	12·36	13·30	14·86	15·04	14·92	14·76	14·52	11·92	11·40	8·26
8	8·80	10·84	12·82	13·00	15·92	16·24	15·28	13·16	15·78	12·00	9·44	10·44
9	8·92	9·98	12·26	14·14	15·42	15·44	14·78	14·54	15·20	12·10	9·96	9·58
10	9·50	9·52	12·68	13·50	15·72	15·36	15·72	15·10	14·52	12·14	10·04	9·84
11	10·22	10·44	12·38	14·88	14·36	16·32	14·68	14·68	15·22	12·16	9·96	9·68
12	9·54	11·20	11·96	14·66	15·10	15·58	15·22	14·86	15·06	12·48	10·56	9·42
13	9·94	10·38	12·24	14·00	15·38	15·68	15·22	14·16	14·48	11·56	10·26	8·98
14	9·44	10·82	12·02	13·64	15·02	16·90	14·66	15·66	15·56	10·76	10·64	10·36
15	10·32	11·10	12·22	13·44	14·66	15·86	14·86	15·00	13·56	11·90	9·64	9·27
16	10·10	9·84	11·74	14·78	15·52	16·66	16·30	13·96	13·64	11·14	10·96	9·04
17	10·56	10·58	12·58	15·08	15·64	15·60	16·30	13·70	14·32	11·14	10·76	9·02
18	9·64	10·44	12·28	14·34	14·50	15·96	15·10	14·44	13·62	10·92	10·78	10·06
19	9·52	10·48	12·80	14·40	14·96	16·98	14·92	13·68	14·14	10·78	10·68	9·48
20	10·52	10·38	11·76	15·16	16·10	17·04	15·88	15·08	13·14	11·70	8·68	8·38
21	10·74	10·36	13·50	14·44	16·16	16·18	15·30	13·12	12·82	11·78	10·55	9·92
22	9·98	11·14	13·62	14·44	16·68	16·48	14·54	14·72	13·68	11·82	9·28	9·62
23	9·32	10·62	12·94	13·36	16·22	16·30	15·48	14·58	13·02	10·86	10·50	9·58
24	9·96	10·24	13·16	14·68	16·28	15·20	14·82	14·98	12·04	10·54	11·02	9·66
25	10·84	11·10	13·26	15·06	15·76	13·98	13·94	15·46	13·02	12·24	9·76	9·72
26	11·18	11·28	12·52	15·54	15·70	16·12	14·78	14·44	12·74	12·84	10·34	9·76
27	10·34	10·98	12·16	15·54	15·62	15·00	14·74	14·28	13·36	11·12	9·26	9·94
28	9·50	10·58	12·48	15·40	15·90	15·50	15·38	15·52	13·32	11·56	9·88	9·68
29	10·22	(8·75)	13·50	16·10	15·62	15·56	14·76	14·94	13·06	11·60	10·06	9·30
30	10·52	...	13·98	15·24	16·08	15·60	14·66	15·04	12·58	10·82	10·22	9·60
31	8·78	...	14·60	...	17·04	...	14·72	14·64	...	10·56	...	10·14
Means	9·86	10·51	12·49	14·45	15·54	15·79	15·06	14·69	13·96	11·70	10·30	9·70

The Mean of the Twelve Monthly Values is 12°·84.

Table XII.

Showing the Smoothed Difference from Mean of Year of the Mean Daily **Range** *of Temperature deduced from Fifty Years' Observation.*

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	*3·2*	*3·2*	*1·8*	**1·6**	**2·9**	**3·6**	**2·6**	**2·5**	**1·6**	**0·1**	*2·4*	***2·0***
2	*3·7*	*2·6*	*1·8*	**1·4**	**3·0**	**2·8**	**2·4**	**2·3**	**1·2**	**0·1**	*2·4*	***2·1***
3	*3·5*	*2·6*	*1·7*	**1·4**	**2·9**	**2·3**	**2·2**	**2·1**	**1·0**	*0·3*	*1·9*	***2·0***
4	*3·3*	*2·4*	*1·6*	**1·0**	**2·6**	**2·5**	**2·1**	**1·8**	**1·5**	*0·4*	*1·7*	***2·7***
5	*3·1*	*2·6*	*1·1*	**0·9**	**2·3**	**2·6**	**2·0**	**1·9**	**1·9**	*0·4*	*1·9*	***2·9***
6	*3·1*	*2·5*	*0·7*	**0·6**	**2·1**	**2·5**	**2·1**	**1·7**	**1·9**	*0·4*	*1·7*	***3·6***
7	*3·2*	*2·4*	*0·5*	**0·5**	**2·4**	**2·6**	**2·1**	**1·3**	**2·1**	*0·6*	*2·4*	***3·4***
8	*3·7*	*2·4*	*0·4*	**0·6**	**2·5**	**2·7**	**2·2**	**1·3**	**2·3**	*0·9*	*2·6*	***3·4***
9	*3·8*	*2·7*	*0·3*	**0·7**	**2·8**	**2·8**	**2·4**	**1·4**	**2·3**	*0·8*	*3·0*	***2·9***
10	*3·3*	*2·9*	*0·4*	**1·3**	**2·3**	**2·9**	**2·2**	**1·9**	**2·1**	*0·7*	*2·9*	***3·2***
11	*3·1*	*2·4*	*0·5*	**1·5**	**2·2**	**2·9**	**2·4**	**2·0**	**2·1**	*0·6*	*2·7*	***3·2***
12	*2·9*	*2·2*	*0·6*	**1·7**	**2·1**	**3·0**	**2·2**	**1·7**	**2·1**	*0·8*	*2·6*	***3·5***
13	*3·2*	*2·0*	*0·8*	**1·3**	**2·3**	**3·2**	**2·2**	**2·1**	**2·2**	*1·2*	*2·3*	***3·3***
14	*2·9*	*2·1*	*0·7*	**0·9**	**2·2**	**3·3**	**2·1**	**2·1**	**1·7**	*1·4*	*2·7*	***3·3***
15	*2·9*	*2·2*	*0·8*	**1·1**	**2·2**	**3·6**	**2·4**	**2·0**	**1·4**	*1·6*	*2·4*	***3·3***
16	*2·5*	*2·3*	*0·7*	**1·6**	**2·4**	**3·2**	**3·0**	**1·4**	**1·0**	*1·4*	*2·4*	***3·7***
17	*2·7*	*2·6*	*0·6*	**1·9**	**2·4**	**3·2**	**3·1**	**1·2**	**1·0**	*1·8*	*2·0*	***3·5***
18	*2·9*	*2·3*	*0·3*	**1·8**	**2·2**	**3·3**	**2·6**	**1·1**	**1·2**	*1·9*	*2·1*	***3·3***
19	*2·9*	*2·4*	*0·6*	**1·8**	**2·3**	**3·8**	**2·5**	**1·6**	**0·8**	*1·7*	*2·8*	***3·5***
20	*2·6*	*2·4*	*0·1*	**1·8**	**2·9**	**3·9**	**2·5**	**1·1**	**0·5**	*1·4*	*2·9*	***3·6***
21	*2·4*	*2·2*	**0·1**	**1·8**	**3·5**	**3·7**	**2·4**	**1·5**	**0·4**	*1·1*	*3·3*	***3·5***
22	*2·8*	*2·1*	**0·5**	**1·2**	**3·5**	**3·5**	**2·3**	**1·3**	**0·3**	*1·4*	*2·7*	***3·1***
23	*3·1*	*2·2*	**0·4**	**1·3**	**3·6**	**3·1**	**2·1**	**1·9**	**0·1**	*1·8*	*2·6*	***3·2***
24	*2·8*	*2·2*	**0·3**	**1·5**	**3·2**	**2·3**	**1·9**	**2·2**	*0·1*	*1·6*	*2·7*	***3·2***
25	*2·2*	*2·0*	**0·1**	**2·3**	**3·1**	**2·3**	**1·7**	**2·1**	*0·2*	*1·0*	*2·5*	***3·1***
26	*2·0*	*1·7*	*0·2*	**2·5**	**2·9**	**2·2**	**1·6**	**1·9**	**0·2**	*0·8*	*3·1*	***3·0***
27	*2·5*	*1·9*	*0·4*	**2·7**	**2·9**	**2·7**	**2·1**	**1·9**	**0·3**	*1·0*	*3·0*	***3·0***
28	*2·8*	*2·1*	*0·1*	**2·8**	**2·9**	**2·5**	**2·1**	**2·1**	**0·4**	*1·4*	*3·1*	***3·2***
29	*2·8*	...	**0·5**	**2·7**	**3·0**	**2·7**	**2·1**	**2·3**	**0·1**	*1·5*	*2·8*	***3·3***
30	*3·0*	...	**1·2**	**3·0**	**3·4**	**2·6**	**1·9**	**2·0**	**0·1**	*1·8*	*2·7*	***3·2***
31	*3·0*	...	**1·5**	...	**3·7**	...	**2·2**	**2·1**	...	*2·5*	...	***3·3***

Note.—The heavy type indicates an excess, and the italic type a defect.

Table XIII.

Showing the Cumulative Variability of Temperature at Edinburgh on each Day of the Year on the Mean of Fifty Years.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	°	°	°	°	°	°	°	°	°	°	°	°	
1	208	151	142	152	165	142	132	117	123	119	156	182	
2	190	192	147	117	148	127	139	98	133	121	134	152	
3	188	133	148	122	139	145	128	115	120	139	163	189	
4	166	144	158	135	144	179	122	132	120	134	160	171	
5	192	139	128	129	167	111	117	118	131	139	151	170	
6	165	158	155	134	139	133	110	142	129	128	179	150	
7	159	149	150	161	153	151	144	128	122	110	139	140	
8	170	163	164	105	131	122	127	128	125	136	167	142	
9	145	138	129	159	145	141	150	116	143	161	160	144	
10	171	159	155	152	123	135	127	118	138	137	163	137	
11	156	152	174	107	133	150	119	127	151	155	117	171	
12	164	151	137	163	113	144	154	146	149	137	125	176	
13	152	152	151	130	154	156	133	121	109	161	150	190	
14	165	156	122	151	141	106	138	136	137	180	141	141	
15	141	156	124	138	140	120	128	122	120	152	166	152	
16	148	144	147	143	135	139	124	128	140	144	156	152	
17	140	129	176	138	145	142	111	131	127	136	164	157	
18	176	139	152	141	145	126	155	132	126	152	169	164	
19	153	155	136	148	162	158	141	139	127	154	170	174	
20	148	144	147	151	155	136	116	128	133	137	169	141	
21	191	141	114	145	137	156	142	137	133	165	148	162	
22	128	160	174	141	129	136	112	130	110	135	160	162	
23	166	140	151	108	135	140	141	143	114	112	156	172	
24	135	132	144	135	153	140	112	96	128	122	146	183	
25	155	110	109	113	144	125	102	134	125	195	139	150	
26	185	134	148	141	157	125	108	146	136	149	164	140	
27	154	128	131	124	148	135	124	146	156	147	143	161	
28	170	168	144	129	127	131	132	112	154	146	165	164	
29	155	(31)	140	137	132	123	130	157	110	165	149	195	
30	179	...	131	149	153	147	104	107	125	155	200	147	
31	165	...	145	...	131	...	135	125	...	112	...	147	
Totals, .	5080	4117	4473	4098	4423	4121	3957	3955	3894	4435	4669	4978	51,300
Mean, .	167	147	144	137	143	137	128	128	130	143	156	161	140·5
Mean Daily Change	3·36	2·94	2·89	2·73	2·85	2·75	2·53	2·56	2·60	2·86	3·11	3·22	2·87

TABLE XIV.

Showing the Smoothed Excess or Defect from Mean of Year of the Cumulative Variability of Temperature deduced from Fifty Years, Observation.

Day.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1	**41**	**28**	**11**	*3*	**10**	*8*	*2*	*24*	*14*	*9*	*7*	**34**
2	**54**	**18**	**5**	*11*	**10**	*3*	*8*	*31*	*16*	*15*	**10**	**33**
3	**40**	**15**	**10**	*16*	**3**	**9**	*11*	*26*	*17*	*10*	**11**	**30**
4	**41**	*2*	**4**	*12*	**9**	**4**	*19*	*19*	*17*	*4*	**17**	**36**
5	**33**	**6**	**6**	*8*	**9**	*0*	*21*	*10*	*14*	*7*	**22**	**23**
6	**31**	**8**	**3**	*0*	**12**	*9*	*17*	*12*	*14*	*15*	**15**	**12**
7	**24**	**16**	**15**	*8*	*0*	*6*	*14*	*8*	*16*	*16*	**21**	**3**
8	**17**	**9**	**7**	**1**	**2**	*3*	*1*	*17*	*11*	*5*	**14**	**1**
9	**21**	**12**	**8**	*2*	*8*	*8*	*6*	*20*	*6*	**4**	**22**	*0*
10	**16**	**9**	**12**	*2*	*7*	**1**	*9*	*21*	**3**	**10**	**6**	**10**
11	**23**	**13**	**14**	*0*	*18*	**2**	*8*	*11*	**5**	**2**	*6*	**20**
12	**16**	**11**	**13**	*4*	*7*	**9**	*6*	*10*	*5*	**10**	*10*	**38**
13	**19**	**12**	*4*	**7**	*5*	*6*	**1**	*7*	*9*	**18**	*2*	**28**
14	**12**	**14**	*9*	*1*	**4**	*14*	*8*	*15*	*19*	**23**	**11**	**20**
15	**10**	**11**	*10*	**3**	*2*	*19*	*11*	*12*	*9*	**18**	**13**	**7**
16	**2**	**2**	**8**	*1*	*1*	*7*	*20*	*14*	*12*	**3**	**21**	**13**
17	**14**	*4*	**17**	*0*	**1**	*5*	*11*	*11*	*10*	**3**	**21**	**17**
18	**15**	*0*	**14**	**1**	**10**	**1**	*5*	*7*	*14*	**6**	**26**	**24**
19	**18**	**5**	**4**	**6**	**13**	*1*	*4*	*8*	*12*	**7**	**28**	**19**
20	**23**	**6**	*9*	**7**	**10**	*9*	*8*	*6*	*10*	**11**	**21**	**18**
21	**15**	**7**	**4**	**5**	*1*	**2**	*18*	*9*	*16*	**5**	**18**	**14**
22	**21**	**6**	**5**	*10*	*7*	**4**	*9*	*4*	*22*	*4*	**14**	**24**
23	**2**	**3**	**15**	*13*	*2*	*2*	*19*	*18*	*24*	*18*	**13**	**31**
24	**11**	*14*	*6*	*22*	**3**	*6*	*23*	*17*	*19*	**2**	**6**	**27**
25	**17**	*16*	*7*	*11*	**10**	*11*	*34*	*16*	*11*	**14**	**9**	**17**
26	**30**	*17*	*12*	*15*	**9**	*13*	*30*	**1**	*2*	**23**	**8**	**9**
27	**29**	**2**	*0*	*10*	**3**	*11*	*20*	*6*	**8**	**6**	**16**	**14**
28	**19**	**5**	*3*	*11*	*5*	*11*	*12*	*3*	*1*	**12**	**11**	**32**
29	**27**	...	*3*	*3*	*4*	*7*	*19*	*16*	*1*	**14**	**27**	**28**
30	**25**	...	*2*	**9**	*2*	*7*	*18*	*11*	*13*	**3**	**33**	**22**
31	**24**	...	**2**	...	**1**	...	*22*	*23*	...	*0*	...	**26**

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XV.

Showing the Percentage Frequency of the Different Winds at Edinburgh on the Mean of 100 *Years.*

	JANUARY.									FEBRUARY.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	6	3	8	13	8	23	31	6	2	6	3	6	11	3	29	37	4	1
2	4	2	3	13	7	17	36	12	6	5	3	7	8	7	24	36	7	3
3	0	1	9	12	5	21	43	3	6	6	2	9	3	7	24	39	8	2
4	6	7	16	8	5	18	29	7	4	2	4	9	3	4	25	43	7	3
5	6	8	12	5	6	21	33	6	3	1	4	7	5	10	26	37	9	1
6	4	7	14	8	6	18	34	8	1	2	4	8	6	10	27	31	9	3
7	5	3	15	5	5	16	37	10	4	4	5	9	4	8	31	34	2	3
8	2	3	14	10	2	22	35	7	5	1	4	8	7	1	20	46	8	5
9	4	2	15	12	3	20	36	4	4	4	5	13	5	9	24	34	5	1
10	6	5	7	12	8	15	31	11	5	4	8	6	9	6	28	29	6	4
11	6	3	14	9	8	14	30	10	6	3	11	10	4	6	23	34	7	2
12	6	3	11	11	10	13	35	8	3	9	5	10	7	11	22	33	3	0
13	6	4	11	12	9	14	33	8	3	6	3	10	9	11	19	34	5	3
14	4	4	17	6	11	20	26	7	5	5	6	6	10	11	20	36	5	1
15	2	5	14	7	9	20	33	5	5	8	1	3	13	7	25	34	4	5
16	4	6	14	13	7	19	27	6	4	2	3	6	12	10	21	37	6	3
17	4	5	10	8	7	30	31	4	1	4	10	5	14	9	19	32	5	2
18	2	5	7	10	11	21	34	6	4	4	8	5	9	9	18	35	11	1
19	1	7	11	8	8	30	29	4	2	2	4	13	7	5	21	32	13	3
20	3	4	8	10	6	21	34	6	8	6	10	9	6	6	27	25	8	3
21	7	6	8	10	8	23	28	7	3	5	3	14	8	6	22	29	8	5
22	4	4	8	6	10	23	36	4	5	3	5	11	6	6	26	30	6	7
23	3	3	7	9	10	26	34	6	2	4	3	14	7	7	22	33	8	2
24	5	4	6	7	8	32	32	5	1	3	10	11	10	8	24	26	6	2
25	2	5	7	6	5	26	40	6	3	3	3	14	8	5	18	33	10	6
26	3	10	10	4	5	29	31	3	5	5	9	17	7	5	20	30	5	2
27	2	3	13	6	10	19	39	5	3	6	5	13	6	4	22	33	11	0
28	3	3	7	4	11	24	35	9	4	4	7	11	5	5	29	30	8	1
29	6	1	9	6	10	24	36	7	1	...	...	...	...	...	...	...	...	...
30	2	2	8	6	4	27	42	8	1	...	...	...	...	...	...	...	...	...
31	4	3	13	4	10	22	36	5	3	...	...	...	...	...	...	...	...	...
Means	4	4	10	8	7	22	34	7	4	4	5	9	8	7	23	34	7	3

TABLE XV.—*continued.*

	MARCH.									APRIL.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	2	10	11	10	3	26	30	6	2	6	7	16	9	9	13	30	8	2
2	3	3	10	6	2	28	36	6	6	5	12	12	11	1	12	32	10	5
3	2	3	14	11	2	23	29	12	4	7	13	14	6	9	14	30	5	2
4	6	4	13	7	10	20	28	7	5	6	7	15	7	1	15	41	5	3
5	6	4	15	7	6	11	40	9	2	4	6	22	8	3	15	31	10	1
6	12	6	15	5	4	18	28	10	2	3	8	17	11	5	18	28	7	3
7	6	4	16	12	6	12	31	11	2	6	10	21	7	2	15	31	5	3
8	6	9	14	7	5	13	35	8	3	6	8	22	11	1	10	26	10	6
9	10	7	9	6	11	10	31	16	0	6	17	26	5	5	11	21	8	1
10	5	8	12	7	5	15	34	13	1	4	13	25	13	3	6	27	7	2
11	8	9	13	10	8	10	31	8	3	9	12	26	10	1	10	22	8	2
12	6	7	11	7	7	18	29	10	5	6	8	22	8	2	14	28	6	6
13	9	5	9	6	6	12	35	15	3	9	10	21	9	1	13	24	8	5
14	3	3	13	10	10	15	32	9	5	5	12	16	11	5	5	26	14	6
15	7	7	14	6	5	14	29	13	5	7	14	17	7	5	15	21	12	2
16	1	5	15	12	7	18	35	7	0	10	10	16	6	2	19	32	4	1
17	4	8	9	11	6	18	34	7	3	9	6	22	7	3	12	30	9	2
18	4	5	18	8	7	13	35	6	4	11	13	18	3	7	10	26	8	4
19	7	11	14	6	5	17	32	7	1	4	13	21	7	8	10	29	5	3
20	7	8	17	11	2	18	25	10	2	6	13	13	7	6	20	26	6	3
21	4	10	10	8	9	11	32	13	3	9	14	19	5	7	21	18	6	1
22	8	7	13	6	5	22	26	10	3	3	18	19	8	5	12	26	8	1
23	10	10	13	8	6	14	29	8	2	4	10	31	8	3	10	21	10	3
24	6	8	24	4	7	10	31	5	5	3	12	28	6	6	8	28	5	4
25	5	6	20	4	2	19	29	9	6	8	20	20	8	4	8	23	4	5
26	4	6	19	9	1	14	33	11	3	9	15	19	4	3	15	21	11	3
27	4	10	21	5	3	13	31	10	3	4	16	26	5	9	10	15	10	5
28	5	11	22	6	6	18	24	7	1	6	18	19	10	3	11	17	14	2
29	9	7	19	5	4	17	31	8	0	6	9	28	4	5	8	26	11	3
30	6	13	10	9	7	18	24	12	1	2	16	24	8	6	7	24	10	3
31	9	9	11	7	5	17	27	10	5	...	...	...	...	...	...	...	...	...
Means	6	7	14	8	6	16	31	9	3	6	12	21	8	4	12	26	8	3

TABLE XV.—*continued.*

	MAY.									JUNE.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	6	16	26	5	3	11	23	6	4	5	9	29	2	4	16	28	6	1
2	7	18	26	5	5	9	22	5	3	2	12	35	1	1	11	32	5	1
3	6	12	35	2	3	12	19	7	4	1	14	34	3	1	14	24	8	1
4	9	10	27	3	1	14	27	4	5	4	11	22	5	1	9	36	6	6
5	6	11	27	3	5	11	25	10	2	4	10	24	5	2	13	34	5	3
6	4	10	34	7	2	11	22	7	3	1	12	26	5	4	19	24	8	1
7	4	13	25	6	5	8	23	10	6	5	9	22	3	5	17	31	4	4
8	6	19	27	5	6	8	20	4	5	8	12	15	4	3	20	26	9	3
9	10	12	27	6	1	14	20	8	2	4	9	25	7	2	15	28	9	1
10	4	13	35	6	2	9	23	6	2	6	9	27	6	2	16	23	8	3
11	4	10	30	9	1	13	25	7	1	4	8	22	6	5	10	35	6	4
12	4	13	26	4	5	11	27	10	0	5	8	22	3	2	14	36	8	2
13	8	16	26	3	4	10	24	5	4	6	9	18	7	3	11	36	9	1
14	3	10	33	9	1	9	22	10	3	5	7	20	6	1	18	32	9	2
15	4	16	29	7	4	9	21	8	2	7	10	24	3	6	13	24	11	2
16	3	10	28	6	5	13	24	8	3	4	11	25	5	4	15	24	9	3
17	6	8	29	7	9	13	19	7	2	4	15	19	7	3	10	30	9	3
18	6	12	27	6	4	19	18	5	3	6	10	23	6	2	8	36	6	3
19	3	17	22	8	4	8	24	12	2	3	7	27	5	6	7	32	9	4
20	6	12	30	8	6	4	26	7	1	6	13	29	5	5	8	29	4	1
21	4	11	28	9	4	13	22	4	5	6	12	22	3	4	16	26	9	2
22	1	12	33	5	3	16	22	4	4	3	5	20	4	3	17	37	9	2
23	1	17	37	2	5	9	20	5	4	5	5	22	6	3	14	34	6	5
24	2	10	29	5	5	14	24	8	3	7	9	19	1	4	10	38	7	5
25	4	12	26	4	5	6	34	4	5	2	10	26	2	7	8	33	8	4
26	4	14	27	6	2	15	23	6	3	5	12	22	4	4	6	39	4	4
27	8	10	26	4	2	9	32	8	1	3	13	24	3	7	9	31	7	3
28	5	12	32	3	3	13	27	4	1	4	13	24	0	4	14	34	4	3
29	2	12	28	4	7	11	28	4	4	5	10	25	2	4	12	28	7	7
30	4	11	27	4	6	16	28	2	2	4	9	25	4	3	15	30	7	3
31	5	9	35	7	4	13	21	4	2	...	...	...	...	...	...	...	...	...
Means	5	13	29	5	4	11	24	6	3	4	10	24	4	4	13	31	7	3

TABLE XV.—*continued.*

	JULY.									AUGUST.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	2	14	22	9	2	13	31	6	1	2	5	15	3	4	13	47	7	4
2	4	18	17	3	6	12	39	5	6	3	6	15	5	9	15	41	3	3
3	2	12	23	2	4	15	36	3	3	1	6	14	5	7	14	40	9	4
4	0	9	8	4	2	12	43	6	6	3	3	18	2	2	14	48	7	3
5	2	5	19	8	6	11	40	4	5	0	5	19	5	4	20	35	9	3
6	3	6	16	9	2	17	37	8	2	9	5	12	4	5	16	40	5	4
7	5	11	18	3	6	16	31	5	5	1	3	19	3	6	24	33	3	8
8	3	11	17	2	6	15	37	5	4	0	5	16	3	6	19	44	2	5
9	3	8	18	5	6	13	36	6	5	2	11	14	1	4	18	40	6	4
10	5	10	16	5	3	8	42	9	2	3	5	17	7	1	15	46	3	3
11	3	16	16	5	3	10	41	3	3	7	5	13	5	5	16	40	6	3
12	2	12	19	2	3	20	33	5	4	4	7	13	3	5	25	31	7	5
13	4	7	18	4	1	14	38	9	5	2	5	20	5	5	23	29	7	4
14	7	7	17	2	3	13	38	8	5	5	6	13	7	6	23	28	7	5
15	3	7	16	7	5	14	40	5	3	2	6	20	7	4	17	31	10	3
16	4	7	18	3	6	14	44	2	2	3	8	17	5	4	16	35	8	4
17	4	3	20	4	7	15	36	8	3	3	9	12	3	4	17	41	9	2
18	2	5	19	6	6	12	38	6	6	4	8	14	6	3	8	43	7	7
19	3	6	22	3	5	13	37	8	3	4	6	20	6	3	12	40	4	5
20	6	3	21	5	5	20	30	6	4	2	11	21	2	5	14	36	5	4
21	1	7	25	2	7	12	39	5	2	1	10	19	6	4	13	34	7	6
22	3	5	26	2	11	17	32	4	0	5	5	22	5	5	18	32	4	4
23	3	7	20	5	5	13	36	7	4	2	3	16	9	4	15	39	8	4
24	3	9	22	2	9	14	31	5	5	3	6	20	4	3	15	36	8	5
25	4	12	18	6	4	16	33	4	3	3	4	22	8	3	12	38	6	4
26	5	12	22	5	6	15	28	5	2	2	7	16	6	6	13	44	5	1
27	3	10	18	2	3	9	39	9	7	3	6	15	4	6	18	34	12	2
28	4	6	17	6	6	15	38	4	4	3	10	12	3	3	15	45	5	4
29	4	6	27	4	3	16	35	5	0	3	7	14	5	2	10	47	7	5
30	2	12	16	6	5	18	30	6	5	5	7	17	1	6	12	41	7	4
31	10	9	19	3	2	15	33	5	4	3	9	14	3	7	11	40	2	11
Means	4	9	19	4	5	14	36	6	.3	3	6	17	5	4	16	39	6	4

TABLE XV.—*continued.*

	SEPTEMBER.									OCTOBER.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	1	6	11	6	6	18	45	4	3	5	8	13	11	6	14	33	7	3
2	6	5	15	7	5	18	32	10	2	6	7	12	5	9	18	34	7	2
3	4	8	17	2	4	20	35	6	4	4	5	14	7	6	15	39	7	3
4	5	9	20	3	5	14	27	13	4	4	9	10	10	6	19	32	8	2
5	5	6	18	5	8	19	33	2	4	2	8	8	8	6	20	37	7	4
6	4	6	15	6	10	15	33	6	5	3	5	14	8	10	23	28	6	3
7	4	6	15	6	9	19	31	6	4	3	11	11	6	12	18	29	8	2
8	4	7	15	6	8	14	39	1	6	7	6	11	10	8	17	31	6	4
9	2	8	12	9	7	18	37	3	4	5	7	9	9	9	14	38	5	4
10	4	9	14	6	6	14	40	3	4	5	8	7	11	9	16	35	5	4
11	3	7	10	8	4	24	35	8	1	7	6	8	16	6	15	30	7	5
12	2	5	15	3	5	21	35	9	5	2	9	9	10	8	21	32	7	2
13	3	7	14	5	5	16	37	10	3	8	5	10	6	6	19	36	7	3
14	5	12	11	9	2	14	34	9	4	7	7	8	8	4	19	37	5	5
15	5	8	12	4	5	24	35	5	2	8	4	8	10	13	18	35	0	4
16	4	4	12	5	7	19	34	6	9	2	4	13	4	7	27	31	9	3
17	6	2	15	5	8	22	28	7	7	7	6	7	6	1	17	40	10	6
18	5	12	12	5	7	12	36	4	7	8	7	5	8	3	22	36	8	3
19	2	7	12	4	9	14	31	9	12	4	8	9	11	7	20	31	8	2
20	1	7	17	8	5	20	40	8	4	5	3	12	9	9	16	34	8	4
21	5	8	18	8	6	18	22	10	5	6	4	10	15	7	21	29	6	2
22	5	8	15	6	9	14	29	9	5	5	4	10	10	6	25	33	7	0
23	5	5	21	4	10	16	27	6	6	4	3	7	11	8	18	44	3	2
24	4	7	19	8	7	21	25	6	3	1	3	13	12	6	21	33	6	5
25	5	9	16	2	9	15	34	9	1	2	5	11	10	10	16	36	8	2
26	5	5	12	5	9	18	33	7	6	7	5	10	10	2	21	30	10	5
27	4	7	11	4	5	22	35	7	5	7	7	15	9	4	19	26	9	4
28	8	7	13	6	7	17	33	4	5	9	6	13	6	8	15	33	7	3
29	7	11	9	7	12	14	30	3	7	6	8	8	9	6	18	33	8	4
30	11	7	12	10	6	18	26	6	4	4	3	15	7	11	17	35	6	2
31	...	...	...	...	...	...	...	...	...	7	4	10	12	3	19	35	8	2
Means	4	7	14	6	7	17	33	7	5	5	6	10	9	7	19	34	7	3

TABLE XV.—*continued.*

	NOVEMBER.									DECEMBER.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	5	1	11	7	7	21	38	7	3	5	5	8	16	7	17	31	8	3
2	2	3	13	12	5	23	29	10	3	5	2	9	6	10	19	40	2	7
3	1	5	13	7	7	15	33	13	6	1	8	8	13	8	19	33	9	1
4	5	4	16	6	6	15	34	7	7	5	6	13	5	8	17	31	10	5
5	3	5	12	6	8	19	37	6	4	5	4	8	8	10	17	39	4	5
6	6	6	11	13	3	19	29	9	4	3	9	11	4	7	21	32	10	3
7	3	2	11	9	8	21	32	10	4	6	5	6	9	11	18	31	11	3
8	7	5	14	7	5	16	32	7	7	5	4	5	6	8	17	42	9	4
9	11	5	8	8	5	15	38	8	2	2	6	9	4	11	17	39	6	6
10	6	5	11	6	6	18	36	7	5	4	6	8	2	14	22	30	7	7
11	9	8	11	8	10	19	24	8	3	5	3	7	8	10	27	30	7	3
12	8	3	11	7	7	20	36	7	1	4	2	7	6	5	32	31	8	5
13	6	6	9	10	5	18	33	8	5	3	3	9	5	6	27	36	4	7
14	10	7	11	7	7	17	27	11	3	4	1	10	8	4	22	35	10	6
15	6	4	12	7	4	18	41	7	1	4	6	6	9	7	22	38	7	1
16	6	5	17	6	4	16	30	11	5	3	5	6	7	9	19	37	11	3
17	6	4	9	2	6	20	33	12	8	7	5	6	6	5	29	29	7	6
18	6	7	10	3	7	25	28	7	7	7	3	11	5	4	29	33	4	4
19	4	2	5	6	5	22	41	12	3	4	2	10	5	6	25	40	6	2
20	3	4	6	12	4	25	37	8	1	6	2	12	10	7	26	27	8	2
21	4	5	3	11	12	18	36	9	2	7	3	13	4	8	21	30	12	2
22	7	2	9	8	8	15	38	5	8	2	7	9	10	9	26	25	9	3
23	3	6	9	7	6	10	44	12	3	9	8	8	7	4	21	30	9	4
24	8	3	8	3	8	20	38	8	4	5	4	13	4	4	23	34	9	4
25	4	2	15	11	5	20	34	7	2	2	1	14	3	4	21	39	9	7
26	5	7	9	5	8	26	30	7	3	3	3	8	11	6	15	42	3	9
27	5	0	9	8	9	17	40	6	6	3	0	9	11	5	20	42	3	7
28	5	3	9	10	11	20	35	4	3	3	1	3	10	8	24	33	6	7
29	3	3	9	7	12	19	36	9	2	3	4	6	13	2	23	36	8	5
30	4	3	11	13	4	23	30	8	4	3	4	10	11	7	24	30	4	7
31	...	...	...	...	...	...	...	...	...	5	5	4	8	6	23	42	6	1
Means	5	4	11	8	7	19	34	8	4	4	4	9	8	7	22	34	7	5

Mean Annual Percentage Frequency of the Winds.—The Mean of the Twelve Monthly Values is—N. 4, N.E. 7, E. 16, S.E. 7, S. 6, S.W. 17, W. 32, N.W. 7, Calm or Var. 4.

TABLE XVI.

Showing the Smoothed **Percentage** *Excess or Defect from Mean of Year of Wind Direction* **deduced** *from* 100 *Years' Observations.*

	JANUARY.									FEBRUARY.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
*1	1	4	11	4	1	4	4	1	1	1	4	7	1	1	8	5	2	2
2	1	5	9	6	1	3	5	0	1	2	4	9	0	0	9	5	1	2
3	1	4	7	4	0	2	4	0	1	0	4	8	2	0	7	7	0	1
4	0	2	4	1	1	3	3	2	0	1	4	8	3	1	8	8	1	2
5	1	0	2	0	0	2	0	0	1	2	3	8	2	2	9	5	1	2
6	1	1	2	1	0	1	3	1	1	2	3	8	2	3	11	2	0	2
7	0	3	2	1	2	2	3	1	1	2	3	8	1	0	9	5	1	0
8	0	4	1	2	3	2	4	0	0	1	2	6	2	0	8	6	2	1
9	0	4	4	4	2	2	2	0	1	1	1	7	0	1	7	4	1	1
10	1	4	4	4	0	1	0	1	1	0	1	6	1	1	8	0	1	2
11	2	3	5	4	3	3	0	3	1	1	1	7	0	2	7	0	2	2
12	2	4	4	4	3	3	1	2	0	2	1	6	0	3	4	2	2	2
13	1	3	3	3	4	1	1	1	0	3	2	7	2	5	3	2	3	3
14	0	3	2	1	4	1	1	0	0	2	4	10	4	4	4	3	2	1
15	1	2	1	2	3	3	3	1	1	1	4	11	5	3	5	4	2	1
16	1	2	3	2	2	6	2	2	1	1	2	11	6	3	5	2	2	1
17	1	2	6	3	2	6	1	2	1	1	0	11	5	3	2	3	0	2
18	2	1	7	2	3	10	1	2	2	1	0	8	3	2	2	1	3	2
19	2	2	7	2	2	7	0	2	1	0	0	7	0	1	5	1	4	2
20	0	1	7	2	1	8	2	1	0	0	1	4	0	0	6	3	3	0
21	1	2	8	2	2	5	1	1	1	1	1	4	0	0	8	4	0	1
22	1	3	8	1	3	7	1	1	1	0	3	3	0	0	6	1	0	1
23	0	3	9	0	3	10	2	2	1	1	1	4	1	1	7	2	0	0
24	1	3	9	0	2	11	3	1	2	1	2	3	1	1	4	1	1	1
25	1	1	8	1	0	12	2	2	1	0	0	2	1	0	4	2	0	1
26	2	1	6	2	1	8	5	2	0	1	1	1	0	1	3	0	2	1
27	1	2	6	2	3	7	3	1	0	1	0	2	1	1	7	1	1	3
28	0	5	6	2	4	5	5	0	1	0	0	4	0	2	9	1	1	3
29	0	5	8	2	2	8	6	1	2	...	...	...	...	...	...	...	...	...
30	0	5	6	2	2	7	6	0	2	...	...	...	...	...	...	...	...	...
31	0	4	7	0	0	9	8	1	2	...	...	...	...	...	...	...	...	...

NOTE.—The heavy type indicates an excess, and the italic type a defect.

* The positive and negative values do not always balance, there being sometimes a difference of one or two per cent. This slight discrepancy results from the smoothing process adopted, 2·3 for example being entered as 2 in the above tables, and so on. The elimination of these fractional residuals would involve the introduction of decimals.

TABLE XVI.—*continued.*

	MARCH.									APRIL.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	*1*	*0*	*5*	*0*	*3*	**11**	*0*	*1*	*0*	**1**	**2**	*3*	**2**	*1*	*3*	*2*	**2**	*0*
2	*2*	*2*	*4*	**2**	*4*	**9**	*0*	**1**	*0*	**2**	**4**	*2*	**2**	*0*	*4*	*1*	**1**	*1*
3	*0*	*4*	*4*	**1**	*1*	**7**	*1*	**1**	**1**	**2**	**4**	*2*	**1**	*2*	*3*	**2**	*0*	*1*
4	**1**	*3*	*2*	**1**	*0*	**1**	*0*	**2**	*0*	**2**	**2**	**1**	*0*	*2*	*2*	**2**	*0*	*2*
5	**4**	*2*	*2*	*1*	**1**	*1*	*0*	**2**	*1*	*0*	*0*	**2**	**2**	*3*	*1*	**1**	*0*	*2*
6	**4**	*2*	*1*	*2*	*1*	*3*	**1**	**3**	*2*	*0*	**1**	**4**	**2**	*3*	*1*	*2*	*0*	*2*
7	**4**	*1*	*1*	*2*	*1*	*3*	**1**	**3**	*2*	**1**	**2**	**4**	**3**	*3*	*3*	*4*	*0*	*0*
8	**3**	*0*	*4*	*2*	**1**	*5*	*0*	**5**	*2*	**2**	**5**	**7**	**1**	*3*	*5*	*6*	**1**	*1*
9	**3**	**1**	*4*	*0*	**1**	*4*	**1**	**5**	*3*	**1**	**6**	**8**	**3**	*3*	*8*	*7*	**1**	*1*
10	**4**	**1**	*5*	**1**	**2**	*5*	*0*	**5**	*3*	**2**	**7**	**10**	**2**	*3*	*8*	*9*	**1**	*2*
11	**2**	**1**	*4*	**1**	**1**	*3*	*1*	**3**	*1*	**2**	**4**	**8**	**3**	*4*	*7*	*6*	*0*	*1*
12	**4**	*0*	*5*	**1**	**1**	*4*	*0*	**4**	*0*	**4**	**3**	**7**	**2**	*5*	*5*	*7*	*0*	*0*
13	**2**	*2*	*5*	**1**	**2**	*2*	*0*	**4**	*0*	**3**	**3**	**4**	**2**	*3*	*6*	*6*	**2**	**2**
14	**2**	*2*	*4*	*0*	**1**	*3*	*0*	**5**	*0*	**3**	**5**	**2**	**2**	*2*	*6*	*8*	**4**	*0*
15	*0*	*2*	*2*	**2**	**1**	*1*	*0*	**3**	*1*	**3**	**5**	*0*	**1**	*2*	*4*	*6*	**3**	*1*
16	*0*	*0*	*3*	**3**	*0*	*0*	**1**	**2**	*1*	**5**	**3**	**2**	*0*	*3*	*2*	*4*	**1**	*2*
17	*1*	*1*	*2*	**3**	**1**	*1*	**3**	*0*	*2*	**6**	**3**	**3**	*2*	*2*	*3*	*3*	*0*	*2*
18	**1**	**1**	*2*	**1**	*0*	*1*	**2**	*0*	*1*	**4**	**4**	**4**	*1*	*0*	*6*	*4*	*0*	*1*
19	**2**	**1**	*0*	**1**	*1*	*1*	*1*	**1**	*2*	**3**	**6**	**1**	*1*	**1**	*4*	*5*	*1*	*1*
20	**2**	**3**	*2*	**1**	*1*	*2*	*2*	**3**	*2*	**2**	**6**	**2**	*1*	**1**	*0*	*8*	*1*	*2*
21	**2**	**1**	*3*	**1**	*1*	*0*	*4*	**4**	*1*	**2**	**8**	**1**	*0*	*0*	**1**	*9*	*0*	*2*
22	**3**	**2**	*4*	*0*	**1**	*1*	*3*	**3**	*1*	**1**	**7**	**7**	*0*	*1*	*3*	*10*	**1**	*2*
23	**4**	**1**	**1**	*1*	*0*	*2*	*3*	**1**	*1*	*1*	**6**	**10**	*0*	*1*	*7*	*7*	**1**	*1*
24	**3**	**1**	**3**	*2*	*1*	*3*	*2*	*0*	*0*	**1**	**7**	**10**	*0*	*2*	*8*	*8*	*1*	*0*
25	**1**	*0*	**5**	*1*	*3*	*3*	*1*	**1**	**1**	**3**	**9**	**6**	*1*	*2*	*7*	*8*	*0*	*0*
26	*0*	*0*	**4**	*1*	*4*	*2*	*1*	**3**	*0*	**3**	**10**	**6**	*1*	*1*	*6*	*12*	**1**	*0*
27	*0*	**2**	**5**	*0*	*3*	*2*	*3*	**2**	*2*	**2**	**9**	**5**	*1*	*1*	*5*	*14*	**5**	*1*
28	**2**	**2**	**5**	*2*	*2*	*1*	*3*	**1**	*3*	**1**	**7**	**8**	*1*	*1*	*7*	*13*	**5**	*1*
29	**3**	**3**	**1**	*0*	*0*	**1**	*6*	**2**	*3*	**1**	**7**	**8**	*0*	*1*	*8*	*10*	**5**	*1*
30	**4**	**3**	*3*	*0*	*1*	*0*	*5*	**3**	*2*	**1**	**7**	**10**	*1*	*1*	*8*	*8*	**2**	*1*
31	**3**	**3**	*4*	**2**	**1**	*1*	*5*	**3**	*1*	...	...	...	...	...	...	...	...	...

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XVI.—*continued.*

	MAY.									JUNE.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	**1**	**10**	**9**	*1*	*1*	*8*	*9*	*0*	*1*	*1*	**3**	**17**	*4*	*3*	*4*	*5*	*2*	*3*
2	**2**	**8**	**13**	*3*	*2*	*6*	*11*	*1*	*0*	*1*	**5**	**17**	*5*	*4*	*3*	*4*	*1*	*3*
3	**3**	**6**	**13**	*4*	*3*	*5*	*9*	*2*	*0*	*2*	**5**	**14**	*4*	*5*	*6*	*1*	*1*	*1*
4	**3**	**4**	**14**	*4*	*3*	*5*	*8*	*0*	*0*	*1*	**5**	**11**	*3*	*5*	*5*	*1*	*1*	*1*
5	**2**	**3**	**13**	*3*	*3*	*5*	*7*	*0*	*1*	*1*	**4**	**8**	*2*	*4*	*3*	*1*	*1*	*1*
6	**1**	**4**	**13**	*2*	*2*	*7*	*9*	**2**	*0*	*1*	**3**	**8**	*3*	*2*	*1*	*2*	*1*	*1*
7	**1**	**7**	**13**	*1*	*2*	*8*	*10*	*0*	**1**	**1**	**4**	**5**	*3*	*2*	**2**	*5*	*0*	*1*
8	**3**	**8**	**10**	*1*	*2*	*7*	*11*	*0*	*0*	**2**	**3**	**5**	*2*	*3*	*0*	*4*	*0*	*1*
9	**3**	**8**	**14**	*1*	*3*	*7*	*11*	*1*	*1*	**2**	**3**	**6**	*1*	*4*	*0*	*6*	**2**	*2*
10	**2**	**5**	**14**	*0*	*5*	*5*	*9*	*0*	*2*	**1**	**2**	**9**	*1*	*3*	*3*	*3*	**1**	*1*
11	*0*	**5**	**14**	*1*	*3*	*6*	*7*	**1**	*3*	**1**	**1**	**8**	*2*	*3*	*4*	*1*	*0*	*1*
12	**1**	**6**	**11**	*2*	*3*	*6*	*7*	*0*	*2*	**1**	**1**	**5**	*2*	*3*	*5*	**4**	**1**	*2*
13	**1**	**6**	**12**	*2*	*3*	*7*	*8*	**1**	*2*	**1**	**1**	**4**	*2*	*4*	*3*	**3**	**2**	*2*
14	**1**	**7**	**13**	*1*	*3*	*8*	*10*	**1**	*1*	**2**	**2**	**5**	*2*	*3*	*3*	*1*	**3**	*2*
15	*1*	**5**	**14**	*0*	*3*	*7*	*10*	**2**	*1*	**1**	**2**	**7**	*2*	*2*	*2*	*5*	**3**	*2*
16	*0*	**4**	**13**	*0*	*0*	*5*	*11*	**1**	*2*	**1**	**5**	**7**	*2*	*2*	*4*	*6*	**3**	*1*
17	**1**	**3**	**12**	*1*	*0*	*2*	*12*	*0*	*1*	**1**	**5**	**6**	*1*	*3*	*6*	*2*	**1**	*1*
18	**1**	**5**	**10**	*0*	*0*	*4*	*12*	**1**	*2*	*0*	**4**	**7**	*1*	*2*	*9*	**1**	**1**	*1*
19	**1**	**7**	**10**	*0*	*1*	*7*	*9*	**1**	*2*	**1**	**3**	**10**	*2*	*2*	*9*	*0*	*1*	*1*
20	*0*	**6**	**11**	**1**	*1*	*9*	*8*	**1**	*1*	**1**	**4**	**10**	*3*	*1*	*7*	*3*	*0*	*2*
21	*0*	**5**	**11**	*0*	*2*	*6*	*9*	*2*	*1*	**1**	**3**	**8**	*3*	*2*	*3*	*1*	*0*	*2*
22	*2*	**6**	**17**	*2*	*2*	*4*	*11*	*3*	*0*	**1**	*0*	**5**	*3*	*3*	*1*	*0*	**1**	*1*
23	*3*	**6**	**17**	*3*	*2*	*4*	*10*	*1*	*0*	**1**	*1*	**4**	*3*	*3*	*3*	**4**	*0*	*0*
24	*2*	**6**	**15**	*3*	*1*	*7*	*6*	*1*	*0*	**1**	**1**	**6**	*4*	*1*	*6*	**3**	*0*	**1**
25	*1*	**5**	**11**	*2*	*2*	*5*	*5*	*1*	*0*	**1**	**3**	**6**	*5*	*1*	*9*	**5**	*1*	*0*
26	**1**	**5**	**10**	*2*	*3*	*7*	*2*	*1*	*1*	*1*	**5**	**8**	*4*	*0*	*9*	**2**	*1*	*0*
27	**2**	**5**	**12**	*3*	*4*	*5*	*5*	*1*	*2*	*0*	**6**	**7**	*5*	*1*	*7*	**3**	*2*	*1*
28	**1**	**4**	**13**	*3*	*2*	*6*	*3*	*2*	*2*	*0*	**5**	**8**	*5*	*1*	*5*	*1*	*1*	*0*
29	*0*	**5**	**13**	*3*	*1*	*4*	*4*	*4*	*2*	**0**	**4**	**9**	*5*	*2*	*3*	*1*	*1*	*0*
30	*0*	**4**	**14**	*2*	*0*	*4*	*6*	*4*	*1*	*0*	**4**	**8**	*2*	*3*	*4*	*2*	*0*	*0*
31	**1**	**3**	**14**	*3*	*1*	*2*	*8*	*3*	*2*	...	...	...	...	...	...	...	...	...

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XVI.—*continued.*

	JULY.									AUGUST.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	*0*	**7**	**5**	**2**	*2*	*3*	**1**	*1*	*1*	**1**	*0*	*0*	*3*	*1*	*3*	**8**	*2*	*0*
2	*1*	**8**	**5**	*2*	*2*	*4*	**3**	*2*	*1*	*2*	*1*	*1*	*3*	**1**	*3*	**11**	*1*	*0*
3	*2*	**6**	**3**	*4*	*2*	*4*	**7**	*2*	**1**	*2*	*2*	*0*	*3*	*0*	*3*	**10**	*1*	*1*
4	*3*	**2**	**4**	*2*	*2*	*4*	**8**	*3*	**1**	*3*	*2*	**1**	*3*	*2*	*1*	**9**	**1**	*1*
5	*2*	*0*	**2**	*0*	*3*	*4*	**8**	*1*	*0*	*0*	*3*	*0*	*3*	*2*	*0*	**9**	*0*	*1*
6	*1*	*0*	**2**	*0*	*1*	*2*	**4**	*1*	*0*	*1*	*3*	**1**	*3*	*1*	**3**	**4**	*1*	**1**
7	*0*	**2**	**1**	*2*	*1*	*1*	**3**	*1*	*0*	*1*	*3*	*0*	*4*	*0*	**3**	**7**	*4*	**2**
8	*0*	**3**	**2**	*4*	*0*	*2*	**3**	*2*	**1**	*3*	*1*	*0*	*5*	*1*	**3**	**7**	*3*	**2**
9	*0*	**3**	**1**	*3*	*1*	*5*	**6**	*0*	*0*	*2*	*0*	*0*	*3*	*2*	*0*	**11**	*3*	*0*
10	*0*	**4**	**1**	*2*	*2*	*7*	**8**	*1*	*1*	*0*	*0*	*1*	*3*	*3*	*1*	**10**	*2*	*1*
11	*1*	**6**	**1**	*3*	*3*	*4*	**7**	*1*	*1*	**1**	*1*	*2*	*2*	*2*	**2**	**7**	*2*	*0*
12	*1*	**5**	**2**	*3*	*4*	*2*	**5**	*1*	*0*	*0*	*1*	*1*	*3*	*1*	**4**	**1**	*0*	*0*
13	*0*	**2**	**2**	*4*	*4*	*1*	**4**	*0*	**1**	*0*	*1*	*1*	*2*	*1*	**7**	*3*	*0*	**1**
14	**1**	*0*	**1**	*3*	*3*	*3*	**7**	*0*	*0*	*1*	*1*	**2**	*1*	*1*	**4**	*3*	**1**	*0*
15	**1**	*0*	**1**	*3*	*1*	*3*	**9**	*2*	*1*	*1*	*0*	**1**	*1*	*1*	**2**	*0*	**1**	*0*
16	*0*	*1*	**2**	*2*	*0*	*3*	**8**	*2*	*1*	*1*	**1**	*0*	*2*	*2*	*0*	**4**	**2**	*1*
17	*1*	*2*	**3**	*3*	*0*	*3*	**7**	*2*	*0*	*1*	**1**	*2*	*2*	*2*	*3*	**8**	**1**	*0*
18	*1*	*2*	**4**	*3*	*0*	*4*	**5**	*0*	*0*	*0*	**1**	*1*	*2*	*3*	*5*	**9**	*0*	**1**
19	*0*	*2*	**5**	*2*	*1*	*2*	**3**	*0*	*0*	*1*	**1**	**2**	*2*	*2*	*6*	**8**	*2*	**1**
20	*1*	*2*	**7**	*4*	*0*	*2*	**3**	*1*	*1*	*2*	**2**	**4**	*2*	*2*	*4*	**5**	*2*	**1**
21	*1*	*2*	**8**	*4*	**2**	*1*	**2**	*2*	*2*	*1*	**2**	**5**	*2*	*1*	*2*	**2**	*2*	**1**
22	*2*	*1*	**8**	*4*	**2**	*3*	**4**	*2*	*2*	*1*	*1*	**3**	*0*	*2*	*2*	**3**	*1*	**1**
23	*1*	*0*	**7**	*4*	**2**	*2*	**1**	*2*	*1*	*1*	*2*	**3**	*1*	*2*	*1*	**4**	*0*	*0*
24	*1*	**2**	**4**	*3*	*0*	*3*	**1**	*2*	*0*	*1*	*3*	**3**	*0*	*3*	*3*	**6**	*0*	*0*
25	*0*	**4**	**5**	*3*	*0*	*2*	*1*	*2*	*1*	*1*	*1*	**3**	*1*	*2*	*4*	**7**	*1*	*1*
26	*0*	**4**	**3**	*3*	*2*	*4*	**1**	*1*	*0*	*1*	*1*	**2**	*1*	*1*	*3*	**7**	**1**	*2*
27	*0*	**2**	**3**	*3*	*1*	*4*	**3**	*1*	*0*	*1*	**1**	*2*	*2*	*1*	*2*	**9**	*0*	*2*
28	*0*	*0*	**5**	*3*	*2*	*4*	**5**	*1*	*0*	*1*	**1**	*2*	*3*	*2*	*3*	**10**	**1**	*0*
29	*1*	**1**	**4**	*1*	*1*	*1*	**2**	*2*	*1*	*0*	**1**	*2*	*4*	*2*	*5*	**12**	*1*	*0*
30	**1**	**2**	**5**	*2*	*3*	*1*	**1**	*2*	*1*	*0*	**1**	*1*	*4*	*1*	*6*	**11**	*2*	**3**
31	**1**	**2**	**1**	*3*	*2*	*2*	**5**	*1*	*0*	*1*	*0*	*2*	*4*	*0*	*3*	**10**	*3*	**2**

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XVI.—*continued.*

	SEPTEMBER.									OCTOBER.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	**2**	*0*	*3*	*2*	*0*	*1*	**7**	*2*	**1**	**1**	*0*	*4*	**2**	**1**	*0*	*1*	*0*	*1*
2	*0*	*1*	*2*	*2*	*1*	**2**	**5**	*0*	*1*	**1**	*0*	*3*	**1**	**1**	*1*	**3**	*0*	*1*
3	**1**	*0*	**1**	*3*	*1*	*0*	*1*	**3**	*1*	**1**	*0*	*4*	*0*	**1**	*0*	**3**	*0*	*2*
4	**1**	**1**	**2**	*4*	*0*	**1**	*0*	*0*	*0*	*1*	*0*	*5*	**1**	*0*	**1**	**4**	*0*	*1*
5	**1**	*0*	**2**	*2*	**2**	*1*	*1*	*0*	*0*	*1*	*0*	*5*	**2**	**1**	**4**	*0*	*0*	*1*
6	*0*	*1*	*0*	*1*	**3**	**1**	*0*	*2*	*0*	*1*	**1**	*5*	*0*	**3**	**3**	*1*	*0*	*1*
7	*0*	*1*	*1*	*1*	**3**	*1*	**2**	*3*	**1**	*0*	**1**	*4*	**1**	**4**	**2**	*3*	*0*	*1*
8	*1*	*0*	*2*	*0*	**2**	*0*	**4**	*4*	**1**	**1**	**1**	*6*	**1**	**4**	*1*	**1**	*1*	*1*
9	*1*	**1**	*2*	*0*	**1**	*2*	**7**	*5*	**1**	**2**	*0*	*7*	**3**	**3**	*1*	**3**	*2*	*0*
10	*1*	**1**	*4*	**1**	*0*	**2**	**5**	*2*	*1*	**2**	*0*	*8*	**5**	**2**	*2*	**2**	*1*	*0*
11	*1*	*0*	*3*	*1*	*1*	**3**	**5**	*0*	*1*	**1**	**1**	*8*	**5**	**2**	*0*	*0*	*1*	*0*
12	*1*	*1*	*3*	*2*	*1*	**3**	**4**	**1**	*1*	**2**	*0*	*7*	**4**	**1**	**1**	**1**	*0*	*1*
13	*1*	**1**	*3*	*1*	*2*	*0*	**3**	**2**	*0*	**2**	*0*	*7*	**1**	*0*	**3**	**3**	*1*	*1*
14	*0*	**2**	*4*	*1*	*2*	**1**	**3**	**1**	*1*	**4**	*2*	*7*	**1**	**2**	**2**	**4**	*3*	*0*
15	**1**	**1**	*4*	*1*	*1*	**2**	**2**	*0*	**1**	**2**	*2*	*6*	*0*	**2**	**4**	**2**	*2*	*0*
16	**1**	*2*	*3*	*2*	**1**	**5**	*0*	*1*	**2**	**2**	*2*	*7*	*0*	**1**	**4**	**3**	*1*	*0*
17	**1**	*1*	*3*	*2*	**1**	**1**	**1**	*1*	**4**	**2**	*1*	*8*	*1*	*2*	**5**	**4**	**2**	*0*
18	*0*	*0*	*3*	*2*	**2**	*1*	*0*	*0*	**5**	**2**	*0*	*9*	**1**	*2*	**3**	**4**	**2**	*0*
19	*1*	**2**	*2*	*1*	**1**	*2*	**4**	*0*	**4**	**2**	*1*	*7*	**2**	*0*	**2**	**2**	**1**	*1*
20	*1*	*0*	*0*	*0*	**1**	*0*	*1*	**2**	**3**	**1**	*2*	*6*	**5**	**1**	**2**	*1*	*0*	*1*
21	*0*	**1**	**1**	*0*	**1**	*0*	*2*	**2**	**1**	**1**	*3*	*5*	**4**	**1**	**4**	*0*	*0*	*2*
22	**1**	*0*	**2**	*1*	**2**	*1*	*6*	**1**	**1**	**1**	*3*	*7*	**5**	**1**	**4**	**3**	*2*	*3*
23	**1**	*0*	**2**	*1*	**3**	*0*	*5*	*0*	**1**	*1*	*4*	*6*	**4**	**1**	**4**	**5**	*2*	*2*
24	**1**	*0*	**3**	*2*	**3**	*0*	*3*	*0*	*1*	*2*	*3*	*6*	**4**	**2**	**1**	**6**	*1*	*1*
25	**1**	*0*	*0*	*2*	**3**	**1**	*1*	*0*	*1*	*1*	*3*	*5*	**4**	*0*	**2**	**1**	**1**	*0*
26	**1**	*0*	*3*	*3*	**2**	**1**	**2**	**1**	*0*	**1**	*1*	*4*	**3**	*1*	**2**	*1*	**2**	*0*
27	**2**	*1*	*4*	*2*	**1**	**2**	**2**	*1*	**1**	**4**	*1*	*3*	**1**	*1*	**1**	*2*	**2**	*0*
28	**2**	**1**	*5*	*1*	**2**	**1**	**1**	*2*	**2**	**3**	*0*	*4*	**1**	*1*	*0*	*1*	**1**	*0*
29	**5**	**1**	*5*	**1**	**2**	*1*	*2*	*3*	**1**	**2**	*1*	*4*	*0*	**2**	*0*	**2**	*0*	*1*
30	**4**	**2**	*5*	**2**	**2**	*0*	*2*	*2*	**1**	**2**	*2*	*5*	**2**	**1**	**1**	**2**	*0*	*1*
31	...	...	...	...	...	...	...	...	...	**1**	*4*	*4*	**2**	**1**	**2**	**4**	*0*	*2*

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XVI.—*continued.*

	NOVEMBER.									DECEMBER.								
Day.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
1	**1**	*4*	*5*	**3**	*1*	**4**	**2**	**1**	*1*	*1*	*4*	*7*	**5**	**1**	*0*	**2**	*1*	**1**
2	*1*	*4*	*4*	**2**	*0*	**3**	**1**	**3**	*0*	*1*	*2*	*8*	**5**	**2**	**1**	**3**	*1*	*0*
3	*1*	*3*	*2*	**1**	*0*	**1**	*0*	**3**	**1**	*0*	*2*	*6*	**1**	**3**	**1**	**3**	*0*	*0*
4	*1*	*2*	*2*	*1*	**1**	*1*	**3**	**2**	**2**	*0*	*1*	*6*	**2**	**3**	**1**	**2**	**1**	*0*
5	**1**	*2*	*3*	**1**	*0*	**1**	**1**	*0*	**1**	*0*	*1*	*5*	*1*	**2**	**1**	**2**	**1**	*0*
6	*0*	*3*	*5*	**2**	*0*	**3**	**1**	**1**	*0*	**1**	*1*	*8*	*0*	**3**	**2**	**2**	**1**	*0*
7	**1**	*3*	*4*	**2**	*1*	**2**	*1*	**1**	**1**	**1**	*1*	*9*	*1*	**3**	**2**	**3**	**3**	*1*
8	**3**	*3*	*5*	**1**	*0*	*0*	**2**	**1**	*0*	*0*	*2*	*9*	*1*	**4**	*0*	**5**	**2**	*0*
9	**4**	*2*	*5*	*0*	*1*	*1*	**3**	*0*	**1**	*0*	*2*	*9*	*3*	**5**	**2**	**5**	*0*	**2**
10	**5**	*1*	*6*	*0*	**1**	*0*	**1**	**1**	*1*	*0*	*2*	*8*	*2*	**6**	**5**	**1**	*0*	**1**
11	**4**	*2*	*5*	*0*	**2**	**2**	*0*	*0*	*1*	*0*	*3*	*9*	*2*	**4**	**10**	*2*	*0*	**1**
12	**4**	*1*	*6*	*1*	**2**	**2**	*1*	**1**	*1*	*0*	*4*	*8*	*1*	**1**	**12**	*0*	*1*	**1**
13	**4**	*2*	*6*	*1*	**1**	**1**	*0*	**2**	*1*	*0*	*5*	*7*	*1*	*1*	**10**	**2**	*0*	**2**
14	**3**	*1*	*5*	*1*	*1*	**1**	**2**	**2**	*1*	*0*	*4*	*8*	*0*	*0*	**7**	**4**	*0*	**1**
15	**3**	*2*	*3*	*0*	*1*	*0*	**1**	**3**	*1*	*0*	*3*	*9*	**1**	**1**	**4**	**5**	**2**	*1*
16	**2**	*3*	*3*	*2*	*1*	**1**	**3**	**3**	**1**	**1**	*2*	*10*	*0*	**1**	**6**	**2**	**1**	*1*
17	**2**	*2*	*4*	*3*	*0*	**3**	*2*	**3**	**3**	**2**	*3*	*8*	*1*	*0*	**9**	**1**	*0*	*0*
18	**1**	*3*	*8*	*3*	*0*	**5**	**2**	**3**	**2**	**2**	*4*	*7*	*2*	*1*	**11**	**2**	*1*	*0*
19	*0*	*3*	*9*	*0*	*1*	**7**	**3**	**2**	*0*	**2**	*5*	*5*	*0*	*0*	**10**	**1**	*2*	*1*
20	*0*	*3*	*11*	**3**	**1**	**5**	**6**	**3**	*2*	**2**	*5*	*4*	*1*	**1**	**7**	*0*	**1**	*2*
21	**1**	*3*	*10*	**3**	**1**	**2**	**5**	*0*	*0*	**1**	*3*	*5*	**1**	**2**	**7**	*5*	**2**	*2*
22	**1**	*3*	*9*	**2**	**2**	*3*	**7**	**2**	*0*	**2**	*1*	*6*	*0*	**1**	**6**	*4*	**3**	*1*
23	**2**	*3*	*7*	*1*	**1**	*2*	**8**	**1**	**1**	**1**	*1*	*6*	*0*	*0*	**6**	*2*	**2**	*0*
24	**1**	*3*	*5*	*0*	*0*	*0*	**7**	**2**	*1*	**1**	*3*	*4*	*2*	*2*	**5**	**2**	**2**	**1**
25	**2**	*3*	*5*	*1*	**1**	**5**	**2**	*0*	*1*	*1*	*4*	*4*	*1*	*1*	**3**	**6**	*0*	**3**
26	**1**	*4*	*5*	**1**	**1**	**4**	**3**	*0*	*0*	*1*	*6*	*6*	**1**	*1*	**2**	**9**	*2*	**4**
27	**1**	*4*	*7*	**1**	**3**	**4**	**3**	*1*	*0*	*1*	*6*	*8*	**4**	*0*	**3**	**7**	*3*	**4**
28	*0*	*5*	*7*	**1**	**5**	**2**	**5**	*1*	*0*	*1*	*5*	*8*	**4**	*1*	**5**	**5**	*1*	**2**
29	*0*	*4*	*6*	**3**	**3**	**4**	**2**	*0*	*1*	*1*	*4*	*8*	**5**	*0*	**7**	**1**	*1*	**2**
30	*0*	*3*	*7*	**5**	**2**	**3**	*0*	**1**	*1*	*0*	*3*	*9*	**4**	*1*	**7**	**4**	*1*	*0*
31	...	...	...	...	...	...	...	...	...	**1**	*3*	*9*	**4**	**1**	**6**	**2**	*2*	*1*

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XVII.

Showing the Total Rainfall Recorded at Edinburgh on each day of the year during Eighty-eight years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
1	5·64	6·59	4·99	4·28	6·76	4·33	5·50	3·61	7·92	7·07	8·62	5·49
2	4·07	8·56	2·96	3·98	3·00	6·46	5·75	5·17	7·60	3·59	5·89	5·50
3	2·63	8·28	3·80	5·57	2·29	5·88	9·08	13·36	6·64	7·54	7·64	5·10
4	7·34	4·93	6·12	3·72	4·17	9·01	5·07	7·80	7·31	7·65	4·44	5·26
5	5·92	3·34	4·74	5·37	3·52	5·51	10·32	6·37	7·00	6·97	11·28	6·56
6	3·17	5·20	3·42	3·59	6·15	5·82	7·89	6·16	10·81	5·67	8·63	7·16
7	4·43	4·72	6·21	3·97	5·59	6·02	6·19	7·24	6·21	9·93	10·20	5·80
8	4·60	4·88	2·69	3·45	3·78	5·94	8·02	8·95	7·13	8·29	6·53	5·72
9	3·37	7·35	6·50	4·53	6·34	3·70	5·59	8·44	5·52	6·07	9·95	10·71
10	5·26	4·66	5·73	5·41	5·38	7·61	5·77	6·22	5·39	8·10	8·85	6·09
11	5·62	5·11	2·98	5·45	8·12	8·29	7·24	6·60	4·63	10·81	3·10	6·46
12	6·16	3·87	4·97	3·43	6·02	5·29	7·51	13·01	7·61	8·70	7·74	5·94
13	5·57	5·64	1·91	4·76	5·05	4·09	9·22	13·08	8·47	8·78	9·39	5·20
14	3·00	5·88	2·30	3·91	5·12	4·41	8·56	10·01	6·26	8·24	7·28	4·95
15	5·60	4·41	5·62	3·98	4·92	4·85	6·07	10·90	6·25	5·41	6·10	5·82
16	5·13	5·48	3·64	4·62	4·24	4·37	8·55	9·27	3·22	5·87	5·85	5·22
17	5·47	4·20	3·87	3·53	7·44	6·48	5·50	9·75	12·68	6·70	11·25	5·38
18	4·40	3·98	3·51	4·19	5·52	5·36	8·22	11·51	6·22	7·08	5·82	7·32
19	5·38	3·85	4·20	3·93	5·34	6·62	7·95	5·94	4·86	6·76	6·82	7·35
20	7·22	3·32	4·59	4·42	2·58	3·65	8·08	5·72	8·70	10·93	6·10	6·52
21	5·85	4·05	3·72	7·59	4·31	5·39	6·86	8·40	8·78	4·57	5·06	8·20
22	3·60	3·89	2·71	6·63	4·14	7·31	6·81	7·93	5·71	9·15	5·33	8·72
23	5·85	2·47	3·08	5·03	6·06	6·90	9·46	4·24	7·29	6·90	5·89	5·67
24	6·75	3·69	3·03	7·56	8·76	5·53	9·84	6·67	8·45	4·87	5·94	4·83
25	6·50	6·59	4·84	6·49	5·64	4·31	8·46	8·01	5·55	6·09	7·70	3·75
26	8·40	8·04	3·55	5·42	5·44	8·75	8·09	6·74	3·88	5·96	9·29	4·42
27	6·31	5·35	3·11	3·94	6·50	4·21	7·84	5·48	4·83	5·51	7·32	5·44
28	6·12	6·16	5·15	6·34	8·66	4·38	9·63	7·04	5·15	4·35	6·17	7·68
29	6·42	...	4·38	4·89	5·63	3·88	8·21	8·57	7·31	6·12	6·37	5·97
30	7·16	...	5·13	4·14	5·18	5·04	9·48	9·41	5·87	7·85	8·02	5·08
31	5·30	...	3·41	...	2·51	...	8·54	10·44	...	4·76	...	5·69
Total	168·24	144·49	126·86	144·12	166·16	169·39	239·30	252·04	203·25	216·29	218·57	189·00

The Mean Annual Rainfall is 25·42 inches.

Table XVIII.

Showing the Smoothed Percentage Excess or Defect from Mean of Year of the Rainfall deduced from Eighty-eight Years' Observations.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	%	%	%	%	%	%	%	%	%	%	%	%
1	*17*	**11**	*36*	*36*	*13*	*27*	*11*	*6*	**41**	*10*	**5**	**4**
2	*33*	**27**	*36*	*25*	*24*	*9*	**10**	**20**	**20**	*1*	**20**	*12*
3	*23*	**18**	*30*	*28*	*38*	**16**	**8**	**43**	**17**	**2**	*2*	*14*
4	*14*	*10*	*20*	*20*	*46*	**11**	**33**	**50**	**14**	**20**	**16**	*8*
5	*11*	*27*	*22*	*31*	*25*	**11**	**27**	**10**	**38**	**10**	**32**	**3**
6	*26*	*28*	*22*	*30*	*17*	*6*	**32**	**7**	**31**	**23**	**63**	**7**
7	*33*	*20*	*33*	*40*	*16*	*3*	**20**	**21**	**31**	**30**	**38**	**2**
8	*32*	*8*	*16*	*35*	*15*	*15*	**7**	**34**	**2**	**32**	**45**	**21**
9	*28*	*9*	*19*	*27*	*16*	*6*	**5**	**28**	*2*	**22**	**38**	**22**
10	*23*	*7*	*17*	*16*	**4**	**6**	**1**	**16**	*15*	**36**	**19**	**26**
11	*8*	*26*	*25*	*22*	**2**	**15**	**12**	**40**	*4*	**50**	**7**	**1**
12	*6*	*21*	*46*	*26*	*0*	*4*	**30**	**77**	**12**	**54**	**10**	*4*
13	*20*	*16*	*50*	*34*	*12*	*25*	**37**	**96**	**22**	**40**	**33**	*12*
14	*23*	*13*	*47*	*31*	*18*	*27*	**30**	**84**	**14**	**22**	**24**	*13*
15	*25*	*14*	*37*	*32*	*22*	*26*	**27**	**63**	*15*	**6**	**5**	*13*
16	*12*	*23*	*28*	*34*	*11*	*15*	**10**	**62**	**20**	*2*	**26**	*11*
17	*18*	*26*	*40*	*33*	*7*	*12*	**21**	**66**	**20**	**7**	**25**	*3*
18	*17*	*35*	*37*	*37*	*0*	*0*	**18**	**48**	**29**	**12**	**30**	**9**
19	*8*	*39*	*34*	*32*	*27*	*15*	**32**	**26**	**7**	**35**	**2**	**15**
20	*0*	*39*	*32*	*14*	*33*	*15*	**24**	**9**	**22**	**21**	*2*	**20**
21	*9*	*40*	*40*	**1**	*36*	*11*	**18**	**20**	**26**	**34**	*10*	**27**
22	*17*	*43*	*48*	**5**	*17*	**6**	**26**	**12**	**18**	**12**	*11*	**23**
23	*12*	*45*	*52*	**5**	**7**	**7**	**42**	**2**	**16**	**14**	*7*	**5**
24	**4**	*31*	*40*	**4**	**11**	*9*	**51**	**3**	**16**	*3*	**6**	*22*
25	**18**	*0*	*38*	**6**	**8**	**1**	**43**	**17**	*3*	*8*	**25**	*29*
26	**15**	**8**	*37*	*14*	*4*	*6*	**33**	**10**	*22*	*5*	**32**	*26*
27	**13**	**6**	*36*	*15*	**12**	*6*	**39**	**5**	*25*	*14*	**24**	*5*
28	**2**	*10*	*31*	*17*	**13**	*32*	**40**	**15**	*6*	*13*	**8**	**4**
29	**7**	...	*20*	*17*	**6**	*27*	**48**	**36**	*0*	*0*	**12**	**2**
30	**3**	...	*30*	*14*	*27*	*22*	**42**	**54**	**10**	**2**	**8**	*9*
31	**4**	...	*30*	...	*35*	...	**18**	**51**	...	**15**	...	*11*

Note.—The heavy type indicates an excess, and the italic type a defect.

TABLE XIX.

Showing the Number of Times Rain (including Snow and Hail) fell on each day of the Year at Edinburgh during Eighty-eight Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	38	45	40	39	35	27	36	38	39	37	43	47
2	33	48	30	31	35	35	37	39	42	38	43	33
3	31	46	35	37	32	34	39	45	48	39	44	38
4	40	36	42	34	32	44	44	45	43	39	39	38
5	40	33	40	38	38	40	46	43	47	41	55	48
6	31	41	45	32	41	37	42	41	42	37	44	48
7	30	42	37	37	35	40	43	37	43	46	37	41
8	32	40	25	30	33	36	40	47	39	52	38	39
9	32	39	44	27	37	31	36	41	42	43	43	40
10	35	40	39	35	36	38	37	44	42	55	41	39
11	30	42	39	34	42	40	37	45	37	45	32	41
12	32	35	35	36	42	43	41	49	38	50	40	38
13	34	41	30	40	35	29	42	55	45	37	36	45
14	28	38	29	35	39	33	45	48	36	47	48	37
15	40	40	44	35	28	32	45	52	35	39	45	39
16	38	35	29	42	39	31	38	50	33	45	34	43
17	32	37	30	40	45	31	34	45	37	38	42	39
18	40	38	41	38	37	35	45	42	33	39	37	45
19	36	35	37	42	40	34	47	34	40	41	36	41
20	45	33	36	31	31	30	44	38	36	48	37	37
21	37	36	31	39	32	33	41	34	49	41	41	44
22	34	41	32	43	38	34	41	39	47	44	35	49
23	29	31	32	41	37	36	45	36	38	38	40	35
24	40	37	34	39	39	47	41	41	40	43	39	29
25	38	42	32	42	35	31	37	39	40	45	36	37
26	45	45	34	37	32	35	47	44	39	42	51	31
27	37	42	27	35	37	38	39	37	41	36	38	34
28	44	36	38	41	45	36	40	45	38	38	38	30
29	46	(12)	36	34	38	31	43	41	37	38	36	39
30	40	...	31	33	35	35	40	46	39	50	43	35
31	45	...	41	...	36	...	43	41	...	41	...	31
Total	1132	1106	1095	1097	1136	1056	1275	1321	1205	1312	1211	1210

The Mean Annual Number of Rainy Days is 161.

TABLE XX.

Showing the Mean Duration of Sunshine at Edinburgh on each Day of the Year on the Mean of Thirty Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
1	1·16	1·90	2·64	3·30	4·78	5·31	4·42	5·05	3·98	3·48	2·22	1·59
2	1·92	1·88	3·71	3·26	5·61	4·99	5·32	5·59	4·57	4·07	1·81	1·26
3	1·22	2·04	3·00	4·15	4·65	3·78	4·14	5·20	4·16	3·87	2·56	1·14
4	0·95	2·46	3·50	4·06	5·45	4·35	5·15	4·31	4·54	3·74	2·23	1·42
5	1·42	2·29	3·24	3·14	5·02	4·40	4·79	4·74	4·26	3·02	3·04	1·10
6	1·38	2·22	3·59	4·43	5·60	5·16	4·80	4·58	4·75	2·98	2·73	1·22
7	1·32	2·32	3·56	3·93	4·95	4·77	4·71	4·25	4·58	3·34	2·20	1·90
8	1·42	3·12	4·65	4·38	5·07	4·61	4·86	3·74	4·87	3·27	2·20	1·35
9	1·02	2·35	3·51	4·39	5·45	4·96	4·07	4·20	4·10	2·82	2·40	1·55
10	1·36	2·03	3·79	4·65	5·57	4·41	5·24	5·15	4·26	3·88	3·00	1·47
11	1·16	2·68	3·86	4·32	4·78	4·98	4·47	4·39	5·09	3·63	2·75	1·43
12	1·17	3·10	3·90	3·57	4·98	4·97	5·13	4·63	4·33	3·57	2·38	1·21
13	1·60	2·50	3·18	3·55	4·83	5·20	3·88	5·20	4·12	2·76	2·02	1·53
14	1·55	2·90	3·05	4·26	4·32	5·92	5·26	5·56	3·64	2·64	1·58	1·05
15	1·36	2·90	3·10	3·86	4·28	4·98	5·00	4·11	4·02	3·00	1·56	1·36
16	1·68	1·98	3·46	4·00	4·80	4·72	4·67	4·09	3·63	3·14	1·71	1·26
17	1·61	2·46	3·03	3·76	3·91	4·20	6·40	3·52	3·92	2·36	1·61	1·37
18	1·46	2·53	3·67	4·26	4·91	5·23	4·38	4·36	3·73	3·00	1·93	0·86
19	2·02	3·18	3·87	4·17	5·17	4·00	4·34	5·07	3·52	3·10	1·57	0·94
20	2·37	2·75	3·22	4·72	4·79	5·69	6·34	4·78	3·78	2·73	1·96	1·32
21	1·83	2·96	3·01	5·05	5·48	6·11	5·19	3·97	3·17	2·52	1·41	1·33
22	1·76	2·83	3·09	4·31	4·54	4·57	5·39	4·29	2·50	3·14	1·72	1·69
23	1·53	2·44	4·10	4·19	5·63	5·34	5·68	5·54	2·75	3·03	2·16	1·78
24	1·79	2·96	4·02	3·71	6·38	4·49	5·55	5·12	3·55	1·95	1·31	1·35
25	2·81	2·30	3·10	4·81	5·53	4·29	5·44	4·60	3·79	3·38	1·48	1·41
26	1·95	2·19	3·60	4·65	5·13	5·61	3·66	3·53	3·95	2·48	1·44	1·37
27	1·99	2·06	3·95	4·46	6·26	5·56	5·59	4·07	3·50	2·89	1·31	1·39
28	1·93	2·69	2·97	4·10	5·42	5·32	5·59	4·15	3·36	3·23	1·29	1·27
29	1·25	...	3·84	4·92	5·87	5·12	4·26	4·95	3·53	1·89	2·08	1·49
30	2·01	...	3·98	5·61	5·93	5·65	5·11	4·67	2·66	1·80	1·66	0·87
31	1·37	...	3·67	...	6·09	...	4·66	3·76	...	2·74	...	1·44
Totals	49·37	70·03	108·86	125·97	161·18	148·69	153·49	141·17	116·61	93·45	59·32	41·72

Table XXI.

Showing the Mean Percentage of the Possible Sunshine Recorded at Edinburgh on each Day of the Year on the Mean of Thirty Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	17	22	25	25	31	31	25	32	29	30	24	22
2	27	22	35	25	36	29	31	35	33	36	20	17
3	17	23	28	32	30	22	24	33	30	34	28	16
4	13	28	32	31	36	25	30	27	33	33	25	20
5	20	26	30	23	32	25	28	30	32	27	34	15
6	19	25	33	33	36	30	28	29	35	27	31	17
7	19	26	32	29	32	28	27	27	34	30	25	27
8	20	35	42	32	32	26	28	24	37	30	25	19
9	14	26	31	32	35	28	24	27	31	26	27	22
10	19	22	34	34	35	26	30	33	33	36	35	21
11	16	29	34	31	30	29	26	29	39	34	32	20
12	16	33	34	26	31	29	30	30	33	33	28	17
13	22	27	27	25	30	30	23	34	32	26	24	22
14	21	31	26	30	27	34	31	37	28	25	19	15
15	18	30	26	27	26	28	29	27	32	29	19	20
16	22	21	29	28	29	27	28	27	29	30	21	18
17	21	25	25	26	24	24	38	24	31	23	20	20
18	19	26	31	30	30	30	26	29	30	30	24	12
19	26	32	32	29	31	23	26	34	28	31	20	14
20	31	28	27	32	29	33	38	33	31	27	35	19
21	23	30	25	35	33	35	31	27	26	25	18	19
22	22	28	25	30	27	26	33	29	20	32	22	25
23	19	24	33	29	34	31	34	38	23	31	28	26
24	22	29	32	25	38	26	34	36	30	20	17	20
25	35	22	25	32	33	25	37	32	32	35	19	20
26	24	21	28	31	31	32	22	25	33	26	19	20
27	24	20	31	30	37	32	34	29	30	30	17	20
28	24	25	23	27	32	30	34	29	29	34	17	18
29	15	...	30	32	35	29	26	35	30	20	28	22
30	24	...	31	37	35	32	32	34	23	19	22	13
31	16	...	28	...	36	...	29	27	...	30	...	21
Means	21	26	30	30	32	28	29	30	31	29	24	19

The Mean of the 12 Monthly Values is 27.

Table XXII.

Showing the Smoothed Excess or Defect from Mean of Year of the Percentage of possible Sunshine on the Mean of Thirty Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	*5*	*7*	**1**	*1*	**8**	**5**	**2**	**5**	**3**	**3**	*2*	*7*
2	*7*	*5*	**2**	*0*	**5**	*0*	*0*	**6**	**4**	**6**	*3*	*9*
3	*8*	*3*	**5**	**2**	**7**	*2*	**1**	**5**	**5**	**7**	*3*	*9*
4	*10*	*1*	**3**	**2**	**6**	*3*	*0*	**3**	**5**	**4**	**2**	*10*
5	*10*	*1*	**5**	**2**	**8**	*0*	**2**	**2**	**6**	**2**	**3**	*10*
6	*8*	*1*	**5**	**1**	**6**	**1**	**1**	**2**	**7**	**1**	**3**	*7*
7	*8*	**2**	**9**	**4**	**6**	**1**	**1**	*0*	**8**	**2**	*0*	*6*
8	*9*	**2**	**8**	**4**	**6**	**1**	*1*	*1*	**7**	**2**	*1*	*4*
9	*9*	**1**	**9**	**6**	**7**	*0*	*0*	**1**	**7**	**4**	**2**	*6*
10	*11*	*1*	**6**	**5**	**6**	**1**	*0*	**3**	**7**	**5**	**4**	*6*
11	*10*	**1**	**7**	**3**	**5**	**1**	**2**	**4**	**8**	**7**	**5**	*8*
12	*9*	**3**	**5**	*0*	**3**	**2**	*1*	**4**	**8**	**4**	**1**	*7*
13	*7*	**3**	**2**	*0*	**2**	**4**	**1**	**7**	**4**	**1**	*3*	*9*
14	*7*	**2**	*1*	*0*	**1**	**4**	**1**	**6**	**4**	*0*	*6*	*8*
15	*7*	*0*	*0*	**1**	*0*	**3**	**2**	**3**	**3**	**1**	*7*	*9*
16	*7*	*2*	*0*	*0*	*1*	*1*	**5**	*1*	**4**	*0*	*7*	*8*
17	*6*	*3*	**1**	**1**	**1**	*0*	**4**	*0*	**3**	**1**	*5*	*10*
18	*5*	**1**	**2**	**1**	**1**	*1*	**3**	**2**	**3**	**1**	*6*	*12*
19	*2*	**2**	**3**	**3**	**3**	**2**	**3**	**5**	**3**	**2**	*1*	*12*
20	*0*	**3**	**1**	**5**	**4**	**3**	**5**	**4**	**1**	**1**	*3*	*10*
21	*2*	**2**	*1*	**5**	**3**	**4**	**7**	**3**	*1*	**1**	*2*	*6*
22	*6*	*0*	**1**	**4**	**4**	**4**	**6**	**4**	*4*	**2**	*4*	*4*
23	*6*	*0*	**3**	**1**	**6**	**1**	**7**	**7**	*3*	**1**	*5*	*3*
24	*2*	*2*	**3**	**2**	**8**	*0*	**8**	**8**	**1**	**2**	*6*	*5*
25	*0*	*3*	**1**	**2**	**7**	**1**	**4**	**4**	**5**	*0*	*9*	*7*
26	**1**	*6*	**1**	**4**	**7**	**3**	**4**	**2**	**5**	**3**	*9*	*7*
27	*3*	*5*	*0*	**2**	**6**	**4**	**3**	**1**	**4**	**3**	*9*	*8*
28	*6*	*4*	**1**	**3**	**8**	**3**	**4**	**4**	**3**	**1**	*6*	*7*
29	*6*	...	**1**	**5**	**7**	**3**	**4**	**6**	*0*	*3*	*5*	*9*
30	*9*	...	**3**	**6**	**8**	**2**	**2**	**5**	**1**	*4*	*3*	*8*
31	*6*	...	**1**	...	**7**	...	**4**	**3**	...	*3*	...	*10*

Note.—The heavy type indicates an excess, and the italic type a defect.

Table XXIII.

Showing the Number of Days on which the Sun Shone at Edinburgh for each Day of the Year during Thirty Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	17	24	21	23	25	28	29	29	27	27	20	19
2	21	20	27	21	27	26	29	28	28	27	21	18
3	17	24	22	24	27	25	28	27	28	26	23	16
4	17	23	24	24	27	27	27	28	27	27	26	13
5	15	24	20	24	27	25	27	28	28	23	28	18
6	17	23	25	26	26	26	28	25	30	22	24	17
7	18	23	25	24	27	25	26	25	24	25	22	17
8	18	27	29	25	25	25	27	27	29	26	22	16
9	17	23	25	26	29	25	28	28	29	24	24	17
10	21	21	25	25	26	27	29	29	28	27	26	17
11	17	23	24	29	26	27	26	26	27	24	25	17
12	18	25	24	27	25	27	27	25	25	24	20	17
13	20	25	28	25	24	27	23	24	25	22	18	17
14	20	19	23	27	28	29	27	27	24	20	17	16
15	19	25	23	25	27	25	28	29	24	24	17	20
16	18	19	23	28	26	27	26	27	26	25	19	19
17	19	21	24	24	25	26	28	25	25	22	21	20
18	20	26	25	22	25	27	27	25	23	23	20	14
19	21	27	25	24	29	30	27	26	25	23	23	15
20	20	21	24	26	28	29	29	26	21	22	23	18
21	20	21	22	24	27	28	24	26	24	22	20	17
22	19	21	22	23	25	25	29	26	24	25	20	21
23	20	26	25	25	25	28	27	29	21	27	23	20
24	20	25	25	23	28	27	27	24	26	20	14	17
25	27	22	22	26	27	26	27	25	27	26	17	17
26	24	21	25	27	24	29	25	24	28	24	21	16
27	21	19	24	26	30	28	26	25	26	22	18	18
28	23	22	22	25	28	28	27	25	27	25	18	18
29	19	...	25	28	28	29	25	28	22	23	25	20
30	24	...	26	27	27	27	27	27	24	23	18	15
31	20	...	22	...	26	...	28	24		24	...	19
Means.	19·6	22·9	24·1	25·1	26·6	26·9	27·0	26·4	25·7	24·0	21·1	17·4

The Mean of the 12 Monthly Values is 23·9.

TABLE XXIV.

Showing the Number of Auroras observed at Edinburgh on each Day of the Year during Eighty-one Years.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	0	3	3	1	1	1	0	0	1	0	1	0
2	0	3	1	0	0	0	0	0	0	2	0	0
3	4	0	2	0	0	0	0	0	2	1	3	1
4	2	2	1	0	0	0	0	0	4	2	2	1
5	2	1	0	2	0	0	0	0	1	0	1	0
6	1	1	0	1	0	0	0	1	1	3	2	0
7	2	3	2	0	1	0	0	0	1	2	3	1
8	0	2	0	2	3	0	0	0	0	0	1	0
9	3	2	1	4	0	0	0	0	3	0	2	1
10	0	1	0	0	0	0	0	1	2	1	1	0
11	1	2	1	0	1	0	0	2	2	0	1	1
12	0	2	3	2	0	0	0	1	0	3	1	3
13	1	1	1	0	1	0	0	1	2	3	2	0
14	2	1	3	0	0	0	0	1	0	3	3	1
15	1	1	2	3	2	0	1	0	1	0	1	0
16	2	0	3	0	0	0	0	0	1	1	0	0
17	0	0	3	2	0	0	0	1	1	1	4	0
18	0	3	1	2	0	0	0	0	1	3	3	0
19	2	3	1	3	0	0	0	2	0	3	1	1
20	1	2	1	2	1	0	0	2	0	2	0	0
21	1	2	1	0	1	0	0	1	4	1	0	0
22	0	1	1	1	0	0	0	0	2	2	4	1
23	0	0	0	0	0	0	0	0	0	1	2	1
24	2	1	2	1	0	0	0	1	2	2	0	0
25	0	2	2	1	1	0	0	0	3	3	0	2
26	1	0	0	0	0	0	0	2	2	0	0	0
27	2	0	1	2	0	0	2	0	1	0	0	2
28	0	1	4	1	0	0	1	2	1	1	0	0
29	0	(1)	2	0	0	0	1	3	3	1	1	0
30	1	...	2	0	0	0	1	0	0	1	...	0
31	2	...	2	...	0	...	...	0	...	3	...	0
Totals	33	41	46	30	12	1	6	21	41	46	39	16

The Mean Annual Number of Auroras is 4.

TABLE XXV.

Showing the Number of Times Snow fell on each Day of the Year at Edinburgh during 125 Years.

SNOW.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	17	22	22	14	5	...	...	...	...	1	3	12
2	17	21	21	12	6	...	...	...	...	0	0	10
3	18	25	19	11	6	...	...	...	...	0	1	9
4	22	19	13	6	3	...	...	...	...	1	3	6
5	23	16	17	8	3	...	...	...	...	0	1	9
6	24	18	21	4	2	...	...	...	...	0	8	11
7	17	22	22	9	3	...	...	...	...	0	0	16
8	11	22	25	9	7	...	...	...	...	1	6	9
9	15	18	21	8	1	...	...	...	...	0	4	14
10	23	19	24	13	4	...	...	...	...	0	3	13
11	23	20	29	9	1	...	...	...	...	0	4	8
12	17	18	23	8	0	...	...	...	...	1	4	11
13	16	21	18	12	0	...	...	...	...	2	4	11
14	16	13	19	7	3	...	...	...	...	1	4	4
15	18	15	24	6	1	...	...	...	...	0	6	9
16	29	20	24	12	3	...	...	...	...	0	6	10
17	19	20	19	4	3	...	...	...	...	2	9	13
18	19	21	13	7	0	...	...	...	...	0	10	11
19	23	22	12	8	2	...	...	...	...	0	8	9
20	21	26	15	4	1	...	...	...	...	1	7	12
21	19	20	21	7	0	...	...	...	...	0	6	10
22	13	14	24	4	0	...	...	...	...	2	7	22
23	20	14	20	1	0	...	...	...	...	1	6	13
24	20	23	27	7	0	...	...	...	...	0	4	15
25	12	19	21	3	0	...	...	...	...	0	10	13
26	22	25	19	1	1	...	...	...	...	3	13	20
27	25	29	19	3	1	...	...	...	...	3	14	17
28	24	18	12	5	0	...	...		...	4	6	19
29	26	(3)	16	1	0	...	...	...	...	1	4	21
30	19	...	10	4	1	...	...	...	...	3	12	16
31	23	...	13	...	0	...	...	...	...	1	...	10
Totals	611	563	603	207	57	...	...	...	...	28	173	383
Means	4·9	4·5	4·8	1·7	0·5	...	...	...	...	0·2	1·2	3·1

The Mean Annual Number of Days with Snow is 21.

Table XXVI.

Showing the Number of Times Hail fell on each Day of the year at Edinburgh during 125 *Years.*

Hail.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	1	5	8	9	12	1	0	0	1	2	2	3
2	3	5	5	10	9	1	3	1	2	2	4	2
3	3	2	3	6	7	1	3	1	3	2	4	1
4	3	2	2	8	3	3	1	1		2	3	3
5	4	0	4	6	8	1	3	2	0	0	4	4
6	4	3	5	8	6	2	3	0	0	1	5	1
7	4	4	8	5	9	4	2	0	1	1	2	1
8	1	2	8	7	9	4	2	1	0	2	1	5
9	3	1	2	9	10	2	0	1	1	0	3	3
10	3	1	9	9	10	1	2	0	1	3	2	3
11	0	2	11	13	5	1	1	1	1	3	0	1
12	2	2	5	11	2	2	1	2	1	4	5	4
13	5	2	3	13	5	1	0	1	0	2	3	0
14	2	4	8	4	6	3	0	1	0	0	2	3
15	4	4	2	7	5	0	1	0	0	2	1	5
16	1	4	6	12	5	3	0	2	0	1	2	2
17	0	2	5	10	4	3	1	0	2	3	2	0
18	1	4	7	10	4	0	1	2	3	3	0	2
19	4	3	3	6	3	4	1	2	1	1	6	5
20	2	3	7	5	3	0	1	0	3	3	1	3
21	1	3	2	3	2	0	2	1	0	3	1	5
22	2	5	8	6	5	1	0	0	3	4	4	2
23	2	2	5	9	3	2	1	0	0	4	1	3
24	2	6	8	12	2	1	0	5	2	4	1	4
25	1	6	10	12	8	2	0	0	3	1	4	3
26	1	11	14	~~10~~	7	0	1	1	2	1	5	4
27	2	4	5	12	7	3	1	2	2	1	2	2
28	1	2	6	10	5	0	1	0	2	3	3	4
29	2	(1)	13	8	6	0	2	1	3	4	7	1
30	4	...	8	9	2	0	2	0	1	2	2	4
31	2	...	10	...	2	...	0	1	...	4	...	3
Totals	69	95	200	259	174	46	36	29	40	68	83	86
Means	0·6	0·8	1·6	2·1	1·4	0·4	0·3	0·2	0·3	0·5	0·7	0·7

The Mean Annual Number of Days with Hail is 10.

TABLE XXVII.

Showing the Number of Times Thunderstorms were Observed on each Day of the Year at Edinburyh during 125 *Years.*

THUNDERSTORMS.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	0	1	1	1	1	6	2	7	2	1	0	0
2	1	0	0	0	2	1	10	8	2	0	1	0
3	0	0	0	0	2	8	5	7	2	0	0	0
4	1	1	0	1	1	8	8	4	7	0	2	0
5	1	0	0	3	4	2	11	5	4	1	0	0
6	0	0	0	0	3	3	7	7	2	1	2	1
7	0	0	0	0	4	5	11	4	3	1	0	0
8	0	0	1	1	2	7	5	8	0	0	1	0
9	0	0	0	1	5	6	7	8	3	0	0	0
10	2	0	1	1	2	7	7	7	2	0	0	0
11	0	0	1	1	3	4	11	8	2	1	0	0
12	0	0	0	1	1	5	5	9	2	0	0	0
13	0	0	0	1	2	4	4	9	0	0	0	0
14	0	0	1	1	9	5	7	4	2	0	0	2
15	1	1	0	0	7	5	9	3	1	0	0	1
16	1	1	1	0	3	7	8	5	1	0	1	0
17	2	1	1	0	6	6	7	2	2	1	0	0
18	1	0	0	0	3	6	3	6	4	1	0	0
19	0	1	0	0	5	6	10	2	1	1	0	0
20	1	0	2	0	3	6	10	7	1	2	0	0
21	1	0	1	0	4	7	6	1	0	0	0	0
22	0	0	0	0	1	7	8	2	2	1	0	0
23	0	0	0	3	4	4	7	0	0	0	0	0
24	0	1	0	3	4	9	10	1	0	0	0	1
25	0	2	1	1	2	7	3	6	0	0	0	0
26	0	0	0	2	3	5	8	5	1	3	0	0
27	1	1	0	2	3	5	7	2	4	0	0	0
28	0	0	0	2	3	5	10	2	3	1	0	1
29	0	0	0	2	2	4	9	2	2	1	0	0
30	4	0	...	3	3	4	5	1	2	2	0	1
31	0	...	0	...	2	...	6	3	...	0	...	0
Totals.	17	10	11	30	99	164	226	145	57	18	7	7
...	0·1	0·1	0·1	0·2	0·8	1·3	1·8	1·2	0·5	0·1	0·1	0·1

The Mean Annual Number of Thunderstorms is 6.

Table XXVIII.

Showing the Number of Times Lightning without Thunder was Observed on each Day of the Year at Edinburgh during 61 *Years.*

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	0	0	1	0	0	0	0	0	1	0	0	0
2	0	0	0	0	0	0	1	0	2	1	0	1
3	0	1	0	0	0	0	1	1	2	0	0	0
4	0	0	0	0	0	1	0	0	1	0	0	0
5	1	0	0	0	0	0	0	0	0	1	0	0
6	1	0	0	0	0	0	0	0	3	0	0	1
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	0	1	1
10	0	0	0	0	0	0	0	0	0	1	0	0
11	0	0	0	1	0	1	1	1	0	0	0	1
12	0	0	0	0	1	0	0	0	0	0	1	0
13	1	0	0	0	0	0	1	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	1	0	0
15	2	1	0	0	1	0	0	1	2	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	1	1	0	0	0	1	1	0	0	0	0
18	1	0	0	0	0	0	0	0	0	0	0	0
19	0	1	0	0	0	0	1	2	2	2	0	0
20	0	0	0	0	0	0	0	1	0	0	0	1
21	1	0	0	0	0	0	1	0	1	0	1	0
22	0	0	0	1	0	0	1	0	0	1	0	0
23	2	0	0	0	0	0	1	0	0	0	0	0
24	0	0	0	0	1	0	0	0	0	0	0	0
25	1	1	0	0	1	0	0	0	0	0	0	0
26	1	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	1	1	0	0	0	0	0	1	1
28	0	0	0	0	1	0	1	1	0	1	0	0
29	0	...	0	0	0	0	1	0	1	0	0	0
30	0	...	0	0	0	0	1	1	0	0	1	0
31	0	...	0	...	0	...	0	2	...	0	...	1
Totals	12	5	2	3	6	2	12	11	16	8	5	8

TABLE XXIX.

Showing the Number of Times Gales were Observed on each Day of the Year at Edinburgh during 125 *Years.*

GALES.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	19	21	21	9	7	4	2	7	9	8	15	12
2	13	23	20	6	6	2	2	5	5	8	14	14
3	17	24	16	12	4	6	4	6	8	11	12	17
4	22	16	16	8	4	5	4	7	7	9	12	17
5	17	18	24	9	6	7	6	10	7	7	13	18
6	17	19	16	7	3	3	3	5	9	11	14	15
7	17	20	13	9	11	5	4	7	6	12	9	13
8	9	10	13	6	6	7	6	6	8	8	13	13
9	18	17	16	7	6	5	5	7	12	4	12	13
10	15	16	16	11	5	3	3	3	9	10	10	15
11	10	14	15	6	4	5	3	2	7	15	7	19
12	15	19	9	6	7	3	3	4	7	11	12	17
13	22	18	19	6	2	4	4	6	5	11	14	17
14	10	14	7	5	6	6	2	5	9	18	7	16
15	15	10	10	6	4	1	5	7	12	10	10	21
16	14	13	14	10	6	4	3	5	6	18	11	17
17	11	17	15	7	5	4	3	3	4	9	17	17
18	16	19	14	5	6	2	3	3	10	12	16	13
19	18	15	11	5	8	6	6	2	8	9	14	16
20	20	16	16	6	4	4	3	2	5	14	17	17
21	19	11	11	11	3	5	1	7	6	15	17	15
22	19	22	14	10	6	7	2	4	7	19	16	16
23	24	13	14	8	5	2	2	5	8	12	11	21
24	27	20	13	7	3	7	2	4	9	10	9	18
25	23	19	6	7	4	6	6	7	10	13	8	12
26	23	17	11	10	3	2	2	4	8	12	18	10
27	24	13	6	8	2	3	3	6	15	19	14	17
28	23	13	10	10	4	2	2	6	12	15	22	17
29	22	(4)	15	7	4	4	5	5	9	9	15	18
30	34	...	8	6	5	6	5	7	11	11	12	16
31	27	...	5	...	3	...	2	6	...	5	...	18
Totals	580	471	414	230	152	130	106	163	248	355	391	495
Means	4·1	3·8	3·3	1·8	1·2	1·0	0·8	1·3	2·0	2·8	3·1	3·9

The Mean Annual Number of Gales is 29.

TABLE XXX.

Showing the Number of Times Fog or Mist was Observed on each Day of the Year at Edinburgh during 125 *Years.*

FOG.

Day.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	4	3	5	2	6	6	4	4	2	8	2	4
2	8	4	6	6	9	4	4	5	5	8	5	4
3	7	4	5	7	9	11	8	5	6	6	4	3
4	1	3	3	6	6	7	5	6	10	4	6	7
5	6	5	4	4	11	10	1	3	5	4	5	4
6	10	3	2	3	8	4	3	7	7	5	3	6
7	5	3	5	6	10	8	8	8	5	6	5	5
8	8	2	4	3	6	2	5	5	8	5	5	6
9	3	1	4	6	5	6	3	5	5	3	6	5
10	12	4	6	6	5	8	6	5	5	4	5	6
11	10	3	3	3	9	11	3	5	5	6	4	4
12	12	3	4	5	5	11	3	4	5	9	5	6
13	9	2	3	6	5	9	3	4	8	3	7	3
14	6	1	5	3	8	4	6	6	9	3	6	2
15	7	2	3	7	9	4	8	4	7	6	7	7
16	5	3	3	5	7	6	4	7	7	5	6	6
17	4	2	3	3	3	11	3	6	8	3	7	4
18	3	3	6	6	7	9	5	6	5	7	5	3
19	3	2	6	5	5	8	5	8	5	6	6	4
20	8	4	5	3	4	5	6	4	2	4	3	3
21	3	5	2	2	7	8	2	6	6	9	4	6
22	2	6	4	2	5	8	4	7	4	4	6	7
23	3	2	2	6	10	9	4	2	5	6	6	6
24	4	5	6	7	10	7	5	5	6	5	7	11
25	4	5	2	8	5	7	7	6	3	4	2	6
26	4	4	3	5	8	7	8	5	6	6	5	5
27	5	1	9	6	7	6	6	3	5	7	3	3
28	2	2	8	7	4	5	3	6	6	8	8	3
29	2	...	6	6	4	8	4	4	10	5	7	5
30	1	...	7	9	0	5	5	3	6	12	1	6
31	4	...	5	...	3	...	2	3	...	4	...	2
	165	87	139	153	200	214	143	157	176	175	152	152
	1·3	0·7	1·1	1·2	1·6	1·7	1·1	1·3	1·4	1·4	1·2	1·2

The Mean Annual Number of Days with Mist or Fog is 15.

TABLE XXXI.

Showing the Smoothed Excess or Defect in Days from Mean Frequency of Hail, Thunderstorms, Gales, Fog, and Snow.

NOTE.—The mean daily frequency of each phenomenon is obtained by dividing the total number of times it has been observed by the number of days in the year. Thus, in the 125 years under review, hail fell on 1185 days, which, divided by 365, gives an average of three per diem. But the smoothed value for January 1 is two, being one below the average. The figure 1 is accordingly entered in the table in italic type.

HAIL.

Days.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	*1*	1	2	7	7	*2*	*2*	*3*	*2*	*1*	*0*	*1*
2	*1*	1	2	5	6	*2*	*1*	*2*	*1*	*1*	*0*	*1*
3	*0*	*0*	*0*	5	3	*1*	*1*	*2*	*1*	*1*	1	*1*
4	*0*	*2*	*0*	4	3	*1*	*1*	*2*	*1*	*2*	1	*0*
5	1	*1*	1	4	3	*1*	*1*	*2*	*2*	*2*	1	*0*
6	1	*1*	3	3	5	*1*	*0*	*2*	*3*	*2*	1	*1*
7	*0*	*0*	4	4	5	*0*	*1*	*3*	*3*	*2*	*0*	*1*
8	*0*	*1*	3	4	6	*0*	*2*	*2*	*2*	*2*	*1*	*0*
9	*1*	*2*	3	5	7	*1*	*2*	*2*	*2*	*1*	*1*	1
10	*1*	*2*	4	7	5	*2*	*2*	*2*	*2*	*1*	*1*	*1*
11	*1*	*1*	5	8	3	*2*	*2*	*2*	*2*	*0*	*1*	*0*
12	*1*	*1*	3	9	1	*2*	*2*	*2*	*2*	*0*	*0*	*1*
13	*0*	*0*	2	6	1	*1*	*3*	*2*	*3*	*1*	*0*	*1*
14	1	*0*	1	5	2	*2*	*3*	*2*	*3*	*2*	*1*	*0*
15	*1*	1	2	5	2	*1*	*3*	*2*	*3*	*2*	*1*	*0*
16	*1*	*0*	1	6	2	*1*	*2*	*2*	*2*	*1*	*1*	*1*
17	*2*	*0*	3	8	1	*1*	*2*	*2*	*1*	*1*	*2*	*2*
18	*1*	*0*	2	6	1	*1*	*2*	*2*	*1*	*1*	*0*	*1*
19	*1*	*0*	3	4	*0*	*2*	*2*	*2*	*1*	*1*	*1*	*0*
20	*1*	*0*	1	2	*0*	*2*	*2*	*2*	*2*	*1*	*0*	1
21	*1*	1	3	2	*0*	*3*	*2*	*3*	*1*	*0*	*1*	*0*
22	*1*	*0*	2	3	*0*	*2*	*2*	*3*	*2*	1	*1*	*0*
23	*1*	1	4	6	*0*	*2*	*3*	*1*	*1*	1	*1*	*0*
24	*1*	2	5	8	1	*1*	*3*	*1*	*1*	*0*	*1*	*0*
25	*2*	5	8	8	3	*2*	*3*	*1*	*1*	*1*	*0*	1
26	*2*	3	7	8	4	*1*	*2*	*2*	*1*	*2*	1	*0*
27	*2*	3	5	8	3	*2*	*2*	*2*	*1*	*1*	*0*	*0*
28	*1*	2	5	7	3	*2*	*2*	*2*	*1*	*0*	1	*1*
29	*1*	...	6	6	1	*3*	*1*	*3*	*1*	*0*	1	*0*
30	*0*	...	7	7	*0*	*3*	*2*	*2*	*1*	*0*	1	*0*
31	1	...	6	...	*1*	...	*2*	*3*	...	*0*	...	*0*

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XXXI.—*continued.*

THUNDERSTORMS.

The mean daily frequency of Thunderstorms is 2.

Days.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	*2*	*2*	*2*	*2*	*0*	**2**	**1**	**5**	*0*	*1*	*2*	*2*
2	*2*	*2*	*2*	*2*	*0*	**1**	**3**	**5**	*0*	*2*	*2*	*2*
3	*1*	*2*	*2*	*2*	*0*	**3**	**6**	**4**	**2**	*2*	*1*	*2*
4	*1*	*2*	*2*	*1*	*0*	**4**	**6**	**3**	**2**	*2*	*1*	*2*
5	*1*	*2*	*2*	*1*	**1**	**4**	**7**	**3**	**2**	*1*	*1*	*2*
6	*2*	*2*	*2*	*2*	**1**	**2**	**8**	**3**	**1**	*1*	*1*	*2*
7	*2*	*2*	*2*	*1*	**1**	**1**	**6**	**4**	*0*	*1*	*1*	*2*
8	*2*	*2*	*2*	*1*	**2**	**3**	**6**	**5**	*0*	*2*	*2*	*2*
9	*1*	*2*	*1*	*1*	**1**	**4**	**4**	**6**	*0*	*2*	*2*	*2*
10	*1*	*2*	*1*	*1*	**1**	**5**	**6**	**6**	*0*	*2*	*2*	*2*
11	*1*	*2*	*1*	*1*	*0*	**4**	**6**	**6**	*0*	*2*	*2*	*2*
12	*2*	*2*	*2*	*1*	*0*	**3**	**5**	**7**	*1*	*2*	*2*	*2*
13	*2*	*2*	*2*	*1*	**2**	**2**	**3**	**5**	*1*	*2*	*2*	*1*
14	*2*	*2*	*2*	*2*	**4**	**3**	**5**	**3**	*1*	*2*	*2*	*1*
15	*1*	*1*	*1*	*2*	**4**	**3**	**6**	**2**	*1*	*2*	*2*	*1*
16	*1*	*1*	*1*	*2*	**3**	**4**	**6**	**1**	*1*	*2*	*2*	*2*
17	*1*	*1*	*1*	*2*	**2**	**4**	**4**	**2**	*0*	*1*	*2*	*2*
18	*1*	*1*	*2*	*2*	**3**	**4**	**5**	**1**	*0*	*1*	*2*	*2*
19	*1*	*2*	*1*	*2*	**2**	**4**	**6**	**3**	*0*	*1*	*2*	*2*
20	*1*	*2*	*1*	*2*	**2**	**4**	**7**	**1**	*1*	*1*	*2*	*2*
21	*1*	*2*	*1*	*2*	**1**	**4**	**6**	**1**	*1*	*1*	*2*	*2*
22	*2*	*2*	*2*	*1*	**1**	**5**	**5**	*1*	*1*	*2*	*2*	*2*
23	*2*	*2*	*2*	*0*	**1**	**4**	**6**	*0*	*1*	*2*	*2*	*2*
24	*2*	*1*	*2*	*0*	**1**	**5**	**5**	**2**	*2*	*2*	*2*	*2*
25	*2*	*1*	*2*	*0*	**1**	**5**	**5**	**2**	*2*	*1*	*2*	*2*
26	*2*	*1*	*2*	*0*	**1**	**5**	**4**	**1**	*0*	*1*	*2*	*2*
27	*2*	*2*	*2*	*0*	**1**	**4**	**6**	*0*	**1**	*1*	*2*	*2*
28	*2*	*1*	*2*	*0*	**1**	**3**	**7**	*0*	**1**	*1*	*2*	*2*
29	*1*	...	*2*	*0*	**1**	**3**	**6**	*0*	*0*	*1*	*2*	*1*
30	*1*	...	*2*	*0*	*0*	**2**	**5**	*0*	*0*	*1*	*2*	*2*
31	*0*	...	*2*	...	...	...	**4**	*0*	...	...	...	*2*

NOTE.—**The heavy** type indicates an excess, and the italic type a defect.

TABLE XXXI.—*continued.*

GALES.

The mean daily frequency of Gales is 10.

Days.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	**7**	**13**	**8**	*3*	*4*	*7*	*7*	*5*	*3*	*1*	**1**	**3**
2	**6**	**12**	**9**	*1*	*4*	*6*	*7*	*4*	*3*	*1*	**4**	**4**
3	**7**	**11**	**7**	*1*	*5*	*6*	*7*	*4*	*3*	*1*	**3**	**6**
4	**9**	**9**	**9**	*0*	*5*	*4*	*5*	*2*	*3*	*1*	**2**	**7**
5	**9**	**8**	**9**	*2*	*6*	*5*	*6*	*3*	*2*	*1*	**3**	**7**
6	**7**	**9**	**8**	*2*	*3*	*5*	*6*	*3*	*3*	*0*	**2**	**5**
7	**4**	**6**	**4**	*3*	*3*	*5*	*6*	*4*	*2*	*0*	**2**	**4**
8	**5**	**6**	**4**	*3*	*2*	*4*	*5*	*3*	*1*	*2*	**1**	**3**
9	**4**	**4**	**5**	*2*	*4*	*5*	*5*	*5*	*0*	*3*	**2**	**4**
10	**4**	**6**	**6**	*2*	*5*	*6*	*6*	*6*	*1*	*0*	*0*	**6**
11	**3**	**6**	**3**	*2*	*5*	*6*	*7*	*7*	*2*	**2**	*0*	**7**
12	**6**	**7**	**4**	*4*	*6*	*6*	*7*	*6*	*4*	**2**	**1**	**8**
13	**6**	**7**	**2**	*4*	*5*	*6*	*7*	*5*	*3*	**3**	**1**	**7**
14	**6**	**4**	**2**	*4*	*6*	*6*	*6*	*4*	*1*	**3**	*0*	**8**
15	**3**	**2**	*0*	*3*	*5*	*6*	*7*	*4*	*1*	**5**	*1*	**8**
16	**3**	**3**	**3**	*2*	*5*	*7*	*6*	*5*	*3*	**2**	**3**	**8**
17	**4**	**6**	**4**	*3*	*4*	*7*	*7*	*6*	*3*	**3**	**5**	**6**
18	**5**	**7**	**3**	*4*	*4*	*6*	*6*	*7*	*3*	*0*	**6**	**5**
19	**8**	**7**	**4**	*5*	*3*	*6*	*6*	*8*	*2*	**2**	**6**	**5**
20	**9**	**4**	**3**	*3*	*4*	*5*	*7*	*6*	*4*	**3**	**6**	**6**
21	**9**	**6**	**4**	*1*	*5*	*5*	*8*	*6*	*4*	**6**	**7**	**6**
22	**11**	**5**	**3**	*0*	*5*	*5*	*8*	*5*	*3*	**5**	**5**	**7**
23	**13**	**8**	**4**	*2*	*5*	*5*	*8*	*6*	*2*	**4**	**2**	**8**
24	**15**	**7**	**1**	*3*	*6*	*5*	*7*	*5*	*1*	**2**	*0*	**7**
25	**15**	**9**	*0*	*2*	*7*	*5*	*7*	*5*	*1*	**2**	**2**	**3**
26	**13**	**6**	*2*	*2*	*7*	*6*	*6*	*4*	**1**	**5**	**3**	**3**
27	**13**	**4**	*1*	*1*	*7*	*8*	*8*	*5*	**2**	**5**	**8**	**5**
28	**13**	**6**	*0*	*2*	*7*	*7*	*7*	*4*	**2**	**5**	**7**	**7**
29	**16**	...	**1**	*2*	*6*	*6*	*6*	*4*	**1**	**2**	**6**	**7**
30	**18**	...	*1*	*3*	*6*	*6*	*6*	*4*	*1*	*2*	**3**	**7**
31	**17**	...	*3*	...	*6*	...	*5*	*3*	...	*0*	...	**8**

NOTE.—**The heavy** type indicates an excess, and the italic type a defect.

TABLE XXXI.—*continued.*

FOG.

The mean daily frequency of Fog is 3.

Days.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	*0*	*1*	*1*	*1*	**3**	*1*	*1*	*1*	*2*	**2**	*1*	*2*
2	**1**	*1*	*0*	*0*	**3**	**2**	*0*	*0*	*1*	**2**	*1*	*1*
3	*0*	*1*	*0*	**1**	**3**	**2**	**1**	*0*	**2**	**1**	*0*	*0*
4	*0*	*1*	*1*	**1**	**4**	**4**	*0*	*0*	**2**	*0*	*0*	*0*
5	**1**	*1*	*2*	*1*	**3**	**2**	*2*	*0*	**2**	*1*	*0*	**1**
6	**2**	*1*	*1*	*1*	**5**	**2**	*1*	**1**	**1**	*0*	*1*	*0*
7	**3**	*2*	*1*	*1*	**3**	*0*	*0*	**2**	**2**	*0*	*1*	**1**
8	*0*	*3*	*1*	*0*	**2**	*0*	*0*	**1**	**1**	*0*	*0*	*0*
9	**3**	*3*	*0*	*0*	*0*	*0*	*0*	*0*	**1**	*1*	*0*	**1**
10	**3**	*2*	*1*	*0*	**1**	**3**	*1*	*0*	*0*	*1*	*0*	*0*
11	**6**	*2*	*1*	*0*	**1**	**5**	*1*	*0*	*0*	**1**	*0*	*0*
12	**5**	*2*	*2*	*0*	**1**	**5**	*2*	*1*	**1**	**1**	*0*	*1*
13	**4**	*3*	*1*	*0*	**1**	**3**	*1*	*0*	**2**	*0*	**1**	*1*
14	**2**	*3*	*1*	*0*	**2**	**1**	**1**	*0*	**3**	*1*	**2**	*1*
15	**1**	*3*	*1*	*0*	**3**	*0*	**1**	**1**	**3**	*0*	**1**	*0*
16	*0*	*3*	*2*	*0*	**1**	**2**	*0*	**1**	**2**	*0*	**2**	**1**
17	*1*	*2*	*1*	*0*	**1**	**4**	*1*	**1**	**2**	*0*	**1**	*1*
18	*2*	*2*	*0*	*0*	*0*	**4**	*1*	**2**	**1**	*0*	**1**	*1*
19	*0*	*2*	**1**	*0*	*0*	**2**	*0*	**1**	*1*	**1**	*0*	*2*
20	*0*	*1*	*1*	*2*	*0*	**2**	*1*	**1**	*1*	**1**	*1*	*1*
21	*1*	*0*	*1*	*3*	*0*	**2**	*1*	**1**	*1*	**1**	*1*	*0*
22	*2*	*1*	*2*	*2*	**2**	**3**	*2*	*0*	*0*	**1**	*0*	**1**
23	*2*	*1*	*1*	*0*	**3**	**3**	*1*	*0*	*0*	*0*	**1**	**3**
24	*1*	*1*	*2*	**2**	**3**	**3**	*0*	*1*	*0*	*0*	*0*	**3**
25	*1*	*0*	*1*	**2**	**3**	**2**	**2**	*0*	*0*	*0*	*1*	**2**
26	*1*	*2*	*0*	**1**	**2**	**2**	**2**	*0*	*0*	**1**	*2*	*0*
27	*1*	*3*	**2**	**1**	**1**	**1**	**1**	*0*	**1**	**2**	*0*	*1*
28	*2*	*2*	**3**	**1**	*0*	**1**	*1*	*1*	**2**	**2**	**1**	*1*
29	*3*	...	**2**	**2**	*2*	**1**	*1*	*1*	**2**	**3**	*0*	*0*
30	*3*	...	**1**	**2**	*3*	**1**	*1*	*2*	**3**	**2**	*1*	*1*
31	*2*	...	*0*	...	*2*	...	*1*	*2*	...	**1**	...	*1*

NOTE—The heavy type indicates an excess, and the italic type a defect.

TABLE XXXI.—*continued.*

NOTE.—As regards Snow the Mean is for the Eight Months October to May, none having fallen during the other Four Months of the Year.

SNOW.

The mean daily frequency of Snow is 11.

Day.	Jan.	Feb.	Mar.	April	May	Oct.	Nov.	Dec.
1	**4**	**11**	**9**	**2**	*5*	*11*	*10*	*0*
2	**6**	**12**	**10**	**1**	*5*	*11*	*10*	*1*
3	**8**	**11**	**7**	*1*	*6*	*11*	*10*	*3*
4	**10**	**9**	**5**	*3*	*7*	*11*	*9*	*3*
5	**12**	**7**	**6**	*5*	*8*	*11*	*7*	*2*
6	**10**	**8**	**9**	*4*	*8*	*11*	*8*	**1**
7	**6**	**10**	**12**	*4*	*7*	*11*	*6*	**1**
8	**3**	**10**	**12**	*2*	*7*	*11*	*8*	**2**
9	**5**	**9**	**12**	*1*	*7*	*11*	*7*	**1**
10	**9**	**8**	**14**	*1*	*9*	*11*	*7*	**1**
11	**10**	**8**	**14**	*1*	*9*	*11*	*7*	*0*
12	**8**	**9**	**12**	*1*	*11*	*10*	*7*	*1*
13	**5**	**6**	**9**	*2*	*10*	*10*	*7*	*2*
14	**6**	**5**	**9**	*3*	*10*	*10*	*6*	*3*
15	**10**	**5**	**11**	*3*	*9*	*11*	*6*	*3*
16	**11**	**7**	**11**	*4*	*9*	*10*	*4*	*0*
17	**11**	**9**	**8**	*3*	*9*	*10*	*3*	*0*
18	**9**	**10**	**4**	*5*	*9*	*10*	*2*	*0*
19	**10**	**12**	**2**	*5*	*10*	*11*	*3*	*0*
20	**10**	**12**	**5**	*5*	*10*	*11*	*4*	*1*
21	**7**	**9**	**9**	*6*	*11*	*10*	*4*	**4**
22	**6**	**5**	**11**	*7*	*11*	*10*	*5*	**4**
23	**7**	**6**	**13**	*7*	*11*	*10*	*5*	**6**
24	**7**	**8**	**12**	*7*	*11*	*11*	*4*	**3**
25	**7**	**11**	**11**	*7*	*11*	*10*	*2*	**5**
26	**9**	**13**	**9**	*9*	*10*	*9*	**1**	**6**
27	**13**	**13**	**6**	*8*	*10*	*8*	*0*	**8**
28	**14**	**12**	**5**	*8*	*11*	*8*	*3*	**8**
29	**12**	...	**2**	*8*	*11*	*8*	*4*	**8**
30	**12**	...	**2**	*8*	*11*	*9*	*2*	**5**
31	**11**	...	**1**	...	*11*	*9*	...	**3**

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XXXII.—*Showing the Five Day Means and Totals of the Meteorological Elements observed at Edinburgh during Periods Ranging from* 30 *to* 125 *years.*

	Mean Barometric Pressure corrected and reduced to 32° and Mean Sea Level.	Temperature in Shade 4 Ft. above Grass.						Wind Direction. Percentage Frequency from the Following Directions.											Total Rainfall.	Bright Sunshine. Percentage of Total Possible.	Number of Days the Following Phenomena were Observed.															
		Mean Max.	Mean Min.	Mean Daily Range.	Mean Daily Variability.	Mean Temperature.	Mean Temperature.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm or Var.	N.W. N. N.E. E.	S.E. S. S.W. W.			Thunderstorms.	Lightning without Thunder.	Snow.	Hail.	Gales.	Fogs.	Auroras.	Rain.	Sunshine.	Thunderstorms.	Lightning without Thunder.	Snow.	Hail.	Gales.	Fogs.	Auroras.
No. of Years.	50	50	50	50	50	50	100	100											88	30	125	61	125	125	125	125	81	88	30	50	50	50	50	50	50	50
	Inches.	°	°	°	°	°	°												Ins.																	
Jan. 1– 5	29·821	41·9	32·6	9·3	3·8	37·2	36·7	4	4	10	10	6	20	35	7	4	25	71	25·60	19	3	1	97	14	88	26	8	182	87	0	1	35	9	32	14	7
,, 6–10	·830	41·3	31·8	9·5	3·2	36·6	36·0	4	4	13	9	5	18	35	8	4	29	67	20·85	19	2	1	90	15	76	38	6	160	93	2	1	35	5	31	16	2
,, 11–15	·851	42·6	32·7	9·9	3·1	37·6	36·4	5	4	14	9	9	16	31	8	4	31	65	25·95	19	1	4	90	13	72	44	5	164	94	0	1	31	3	24	22	3
,, 16–20	·795	43·2	33·1	10·1	3·1	38·2	37·2	3	5	10	10	8	24	31	5	4	23	73	27·60	24	5	1	111	8	79	23	5	191	98	2	1	27	4	39	9	2
,, 21–25	·775	42·8	32·5	10·3	3·1	37·6	37·1	4	4	7	8	8	26	34	6	3	21	76	28·55	24	1	4	84	8	112	16	3	178	106	1	3	25	3	47	8	2
,, 26–30	·726	44·1	33·7	10·4	3·4	38·9	37·8	3	4	9	5	8	25	37	6	3	22	75	34·41	22	5	1	116	10	126	14	4	212	111	2	0	38	3	61	4	4
Feb. ,, 31– 4	·751	44·1	34·2	9·9	3·1	39·2	37·9	5	3	9	6	6	25	38	6	2	23	75	33·66	22	2	1	110	16	111	18	10	220	111	2	1	39	10	56	4	8
Feb. 5– 9	·828	43·8	33·4	10·4	3·0	38·6	38·3	2	4	9	5	8	26	36	7	3	22	75	25·49	28	0	0	96	10	84	14	9	195	120	0	0	26	4	37	8	6
,, 10–14	·854	43·7	33·3	10·4	3·0	38·5	38·3	5	7	8	8	9	23	33	5	2	25	73	25·14	28	0	0	91	11	81	13	7	196	113	0	0	41	3	32	7	2
,, 15–19	·879	44·9	34·4	10·5	2·9	39·6	38·7	4	5	6	11	8	21	34	8	3	23	74	21·92	27	4	3	98	17	74	12	7	185	118	1	0	33	6	22	7	5
,, 20–24	·900	44·8	34·3	10·5	2·9	39·6	38·9	4	6	12	7	7	24	29	7	4	29	67	17·42	28	1	0	97	19	82	22	6	178	114	1	0	32	7	24	11	5
Mar. ,, 25– 1	·844	44·2	33·3	10·9	2·7	38·8	38·9	4	7	13	7	5	23	31	8	2	32	66	31·13	23	4	2	113	31	83	17	6	205	105	2	2	50	7	25	11	5
March 2– 6	·888	45·9	34·3	11·6	2·9	40·1	39·4	6	4	13	7	5	20	32	9	4	32	64	21·04	32	0	0	91	19	92	20	4	192	118	0	0	29	3	38	9	2
,, 7–11	·810	46·1	33·6	12·5	3·1	39·8	39·5	7	8	13	8	7	12	32	11	2	39	59	24·11	35	3	0	121	38	73	22	4	184	128	2	0	48	10	32	12	2
,, 12–16	·836	46·1	33·8	12·3	2·7	40·0	40·2	5	6	12	8	7	15	32	11	4	34	62	18·44	28	2	0	108	24	59	18	12	167	121	2	0	46	10	23	7	8

Mar. 17–21	·872	47·2	34·6	12·6	2·9	40·9	41·2	5	8	12	9	6	16	32	9	3	34	63	19·89	28	4	1	80	24	67	22	7	175	120	4	1	30	6	24	14	5
,, 22–26	·852	48·0	34·9	13·1	2·9	41·4	41·2	7	7	18	6	4	16	29	9	4	41	55	17·19	29	1	0	111	45	58	17	5	164	119	1	0	42	11	18	7	3
,, 27–31	·792	48·8	35·4	13·4	2·8	42·1	42·2	7	10	17	6	5	17	27	9	2	43	55	21·18	29	0	0	70	42	44	35	11	173	119	0	0	20	13	14	14	8
April 1– 5	·781	50·8	36·8	14·0	2·6	43·8	43·2	5	9	16	8	5	14	33	7	3	37	60	22·92	27	5	0	51	39	44	25	3	179	116	2	0	11	11	16	15	2
,, 6–10	·894	50·5	36·9	13·6	2·8	43·7	43·8	5	11	22	9	3	12	27	8	3	46	51	20·95	32	3	0	43	38	40	24	7	161	126	1	0	13	14	12	15	3
,, 11–15	·919	50·7	36·6	14·1	2·8	43·6	44·1	7	11	21	9	3	11	24	10	4	49	47	21·53	28	4	1	42	48	29	24	5	180	133	2	1	14	14	9	11	4
,, 16–20	·904	53·2	38·4	14·8	2·9	45·8	45·3	8	11	18	6	5	14	29	6	3	43	54	20·69	29	0	0	35	43	33	22	9	193	124	0	0	10	8	12	14	6
,, 21–25	·887	52·9	38·5	14·4	2·6	45·7	45·9	5	15	23	7	5	12	23	7	3	50	47	33·30	30	7	1	22	42	43	25	3	204	121	1	1	4	9	14	18	1
,, 26–30	·942	54·1	38·5	15·6	2·7	46·3	46·9	6	15	23	6	5	10	21	11	3	55	42	24·73	31	11	1	14	49	41	33	3	180	133	7	0	2	17	8	13	3
May 1– 5	·937	55·0	39·4	15·6	3·1	47·2	47·6	7	14	28	4	3	11	23	6	4	55	41	21·74	33	10	0	23	39	27	41	1	172	133	3	0	7	10	10	16	1
,, 6–10	·908	55·6	40·3	15·3	2·8	48·0	48·2	6	13	30	6	3	10	22	7	3	56	41	27·14	34	16	0	17	44	31	34	4	182	133	8	0	5	16	15	16	4
,, 11–15	·968	56·4	41·5	14·9	2·7	49·0	48·9	5	13	29	6	3	10	24	8	2	55	43	29·23	29	22	2	5	23	23	36	4	186	130	7	2	0	7	10	20	4
,, 16–20	·868	58·0	42·6	15·4	3·0	50·3	50·6	5	12	27	7	6	11	22	8	2	52	46	25·12	29	20	0	9	19	29	26	1	192	133	11	0	3	7	6	13	1
,, 21–25	·943	59·9	43·9	16·0	2·8	51·9	51·9	3	12	31	5	4	12	24	5	4	51	45	28·91	33	15	2	0	20	21	37	2	181	132	8	0	0	7	5	17	2
,, 26–30	·931	60·2	44·5	15·7	2·9	52·4	52·6	4	12	28	4	4	13	28	5	2	49	49	31·41	34	14	2	3	27	18	23	0	187	137	6	1	0	10	8	8	0
June 31– 4	·952	61·6	45·7	15·9	2·9	53·6	53·8	4	13	31	3	2	11	28	6	2	54	44	28·19	29	25	1	0	8	20	31	1	176	132	11	1	0	3	8	14	1
June 5– 9	·895	62·0	46·5	15·5	2·6	54·2	54·3	5	10	22	5	3	17	29	7	2	44	54	26·99	28	23	0	0	13	27	30	0	184	126	14	0	0	6	8	11	0
, 10–14	·911	62·7	46·7	16·0	2·8	54·7	55·2	5	8	22	6	3	14	32	8	2	43	55	29·69	30	25	1	0	8	21	43	0	183	137	14	0	0	4	13	13	0
,, 15–19	·974	64·0	47·8	16·2	2·7	55·9	56·2	5	10	24	5	4	11	29	9	3	48	49	27·68	26	30	0	0	10	17	39	0	163	135	15	0	0	4	5	22	0
,, 20–24	·929	65·1	48·9	16·2	2·8	57·0	56·8	5	9	22	4	4	13	33	7	3	43	54	28·78	30	33	0	0	4	25	37	0	180	137	18	0	0	0	9	22	0
,, 25–29	·950	65·2	50·0	15·2	2·6	57·6	57·5	4	12	24	2	5	10	33	6	4	46	50	25·53	30	26	0	0	5	17	33	0	171	140	13	0	0	2	11	14	0
July ,, 30– 4	·895	65·2	50·0	15·2	2·7	57·6	57·6	2	12	21	4	3	13	36	5	4	40	56	30·04	28	29	2	0	7	18	26	0	191	140	17	2	0	4	7	10	0
July 5– 9	·839	65·3	50·3	15·0	2·6	57·8	58·0	3	8	18	5	5	15	36	6	4	35	61	38·01	27	41	0	0	10	24	20	0	207	136	28	0	0	7	12	9	0
,, 10–14	·900	65·9	50·8	15·1	2·7	58·4	58·6	4	10	17	4	3	13	38	7	4	38	58	38·30	28	34	2	0	4	15	21	0	202	132	11	1	0	2	6	9	0

TABLE XXXII.—*continued.*

	Mean Barometric Pressure corrected and reduced to 32° and Mean Sea Level.	Temperature in Shade 4 Ft. above Grass.						Wind Direction. Percentage Frequency from the Following Directions.											Total Rainfall.	Bright Sunshine. Percentage of Total Possible.	Number of Days the Following Phenomena were Observed.																
		Mean Max.	Mean Min.	Mean Daily Range.	Mean Daily Variability.	Mean Temperature.	Mean Temperature.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm or Var.	N.W. N. N.E. E.	S.E. S. S.W. W.			Thunderstorms.	Lightning without Thunder.	Snow.	Hail.	Gales.	Fogs.	Auroras.	Rain.	Sunshine.	Thunderstorms.	Lightning without Thunder.	Snow.	Hail.	Gales.	Fogs.	Auroras.
No. of Years.	50	50	50	50	50	50	100	100											88	30	125	61	125	125	125	125	81	88	30	50	50	50	50	50	50	50
	Inches.	°	°	°	°	°	°												Ins.																	
July 15–19	·888	66·2	50·7	15·5	2·6	58·4	58·9	3	6	19	4	6	14	39	6	3	34	63	36·29	29	37	2	0	4	20	25	1	209	136	15	0	0	4	5	14	1
,, 20–24	·841	66·1	50·9	15·2	2·5	58·5	58·7	3	6	23	3	8	15	34	5	3	37	60	41·05	34	41	3	0	4	10	21	0	212	136	20	2	0	2	2	11	0
,, 25–29 Aug.	·882	65·2	50·5	14·7	2·4	57·8	58·5	4	9	21	5	4	14	35	5	3	39	58	42·23	31	37	2	0	5	18	28	4	206	130	14	2	0	1	3	9	3
,, 30– 3	·873	65·3	50·3	15·0	2·3	57·8	58·3	4	8	16	4	5	15	38	6	4	34	62	40·16	32	33	2	0	4	25	21	1	205	139	9	0	0	1	8	15	1
Aug. 4– 8	·820	65·5	51·1	14·4	2·6	58·3	58·8	2	4	17	3	5	19	40	5	5	28	67	36·52	27	28	0	0	4	35	29	1	213	133	13	0	0	2	9	12	1
,, 9–13	·840	65·7	51·0	14·7	2·5	58·4	58·5	4	7	15	4	4	19	37	6	4	32	64	47·35	31	41	1	0	5	22	23	5	234	132	26	0	0	3	5	13	4
,, 14–18	·858	65·4	50·9	14·5	2·6	58·2	58·0	4	7	15	6	4	16	36	8	4	34	62	51·44	29	20	2	0	5	23	29	2	237	133	8	2	0	2	9	19	0
,, 19–23	·869	64·3	50·0	14·3	2·7	57·2	57·4	3	7	20	5	4	14	36	6	5	36	59	32·23	32	12	3	0	3	20	27	5	181	133	5	0	0	3	9	15	3
,, 24–28 Sept.	·861	64·2	49·3	14·9	2·5	56·8	56·8	3	7	17	5	4	15	39	7	3	34	63	33·94	30	16	1	0	8	27	25	5	206	123	7	1	0	5	8	10	4
,, 29– 2	·874	63·5	48·9	14·6	2·6	56·2	56·3	4	7	14	4	5	14	41	6	5	31	64	43·94	32	10	6	0	4	32	17	4	209	134	7	3	0	3	14	5	3
Sept. 3– 7	·884	63·1	48·7	14·4	2·5	55·9	55·7	4	7	17	4	7	18	32	7	4	35	61	38·07	33	18	6	0	6	37	33	9	223	137	11	4	0	1	8	10	6
,, 8–12	·895	62·8	47·6	15·2	2·8	55·2	54·8	3	7	13	7	6	18	37	5	4	28	68	30·28	35	9	1	0	4	43	28	7	198	138	0	1	0	0	19	12	2
,, 13–17	·945	61·9	47·6	14·3	2·5	54·8	54·6	4	7	13	6	5	19	34	7	5	31	64	36·88	30	6	2	0	2	36	39	5	186	124	4	0	0	1	9	21	4
,, 18–22	·895	59·3	45·9	13·4	2·5	52·6	52·7	3	8	15	6	7	15	31	8	7	34	59	34·27	27	8	3	0	10	36	22	7	205	117	3	1	0	7	13	13	5
,, 23–27	·859	58·8	45·9	12·9	2·6	52·4	52·3	4	7	16	5	8	18	31	7	4	34	62	30·00	30	5	1	0	9	50	25	8	198	128	4	1	0	3	20	11	6

Sept. 28– Oct. 2	·792	57·5	44·4	13·1	2·5	51·0	51·0	7	8	12	8	9	16	31	5	4	32	64	28·99	30	8	2	1	7	48	38	6	189	127	3	2	0	5	27	14	5
Oct. 3–7	·858	55·6	43·2	12·4	2·6	49·4	49·7	3	8	11	8	8	19	33	7	3	29	68	37·76	30	3	1	1	6	50	25	8	202	123	3	1	1	4	15	12	3
,, 8–12	·785	54·9	42·7	12·2	2·9	48·8	48·8	5	7	9	11	8	17	33	6	4	27	69	41·97	32	1	1	2	12	48	27	4	245	125	1	1	1	6	14	18	2
,, 13–17	·790	53·4	42·1	11·3	3·1	47·8	48·0	7	5	9	7	6	20	36	6	4	27	69	35·00	27	1	1	5	8	66	20	8	206	113	1	1	1	4	28	15	5
,, 18–22	·771	52·1	40·7	11·4	3·0	46·4	46·8	6	5	9	11	6	21	33	7	2	27	71	38·49	29	5	3	3	14	69	30	11	213	115	5	1	1	10	19	17	7
,, 23–27	·747	50·6	39·4	11·2	2·9	45·0	43·3	4	5	11	10	6	19	34	7	4	27	69	29·33	28	3	0	7	11	66	28	6	204	119	2	0	5	3	28	12	6
,, 28– Nov. 1	·811	49·8	38·9	10·9	2·9	44·4	44·3	6	5	11	8	7	18	35	7	3	29	68	31·70	25	4	1	12	15	55	31	7	210	115	2	1	3	7	19	10	4
Nov. 2– 6	·824	49·5	38·6	10·9	3·1	44·0	43·8	3	5	13	9	6	18	32	9	5	30	65	37·88	28	5	0	13	20	65	23	8	225	122	2	0	2	6	19	10	6
,, 7–11	·875	47·6	37·4	10·2	3·0	42·5	42·3	7	5	11	8	7	18	32	8	4	31	65	38·63	29	1	1	17	8	51	25	8	191	119	1	1	11	4	21	15	4
,, 12–16	·853	46·4	36·0	10·4	3·0	41·2	41·2	7	5	12	7	5	18	34	9	3	33	64	36·36	22	1	1	24	13	54	31	7	203	91	1	1	12	5	21	22	5
,, 17–21	·853	46·4	36·1	10·3	3·3	41·2	40·5	5	4	7	7	7	22	35	9	4	25	71	35·05	23	0	1	40	10	81	25	8	193	107	0	1	9	2	28	13	6
,, 22–26	·666	45·2	35·0	10·2	3·1	40·1	39·7	5	4	10	7	7	18	37	8	4	27	69	34·15	21	0	0	40	15	52	26	6	201	95	0	0	13	4	22	18	3
,, 27– Dec. 1	·765	44·7	34·8	9·9	3·4	39·8	39·6	4	3	9	11	9	19	34	7	4	23	73	33·37	21	0	2	48	17	75	23	1	202	98	0	2	17	3	32	16	1
Dec. 2– 6	·811	45·4	35·0	10·4	3·3	40·2	39·6	4	6	10	7	9	18	35	7	4	27	69	29·58	17	1	2	45	11	81	24	2	205	82	0	1	18	4	36	12	2
,, 7–11	·831	44·5	35·0	9·5	2·9	39·8	39·5	4	5	7	6	11	20	35	8	4	24	72	34·78	22	0	2	60	13	73	26	3	200	84	0	1	26	4	36	14	3
,, 12–16	·822	44·1	34·7	9·4	3·2	39·4	39·4	4	4	8	7	6	24	35	8	4	24	72	27·13	18	3	1	45	14	88	24	4	202	89	1	0	19	4	36	11	3
,, 17–21	·781	43·4	34·0	9·4	3·2	38·7	38·7	6	3	11	6	6	26	32	7	3	27	70	34·77	17	0	1	55	15	78	20	1	206	84	0	0	28	8	22	9	0
,, 22–26	·886	42·3	32·6	9·7	3·2	37·4	37·3	4	5	10	7	5	21	34	8	6	27	67	27·39	22	1	0	83	16	77	35	4	181	91	1	0	25	4	28	17	2
,, 27–31	·876	42·7	32·9	9·8	3·3	37·8	37·0	3	3	7	11	6	23	37	5	5	18	77	29·86	19	2	2	83	14	86	19	2	169	90	2	1	26	4	33	16	0

TABLE XXXIII.—*Showing the Mean Temperature and Wet Bulb Depression of the Different Winds at Edinburgh on the Mean of Seven Years. Hours of Observation, 9 a.m. and 9 p.m.*

	N.		N.E.		E.		S.E.		S.		S.W.		W.		N.W.		Calm.		Mean.		Difference between the Extremes.	
	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.	Temp.	Wet Bulb Dep.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January, .	33·5	1·7	33·2	1·4	33·5	1·2	33·2	1·2	39·4	2·1	42·1	2·4	40·4	1·9	33·3	1·9	35·1	1·2	38·3	1·8	8·9	1·2
February, .	33·7	1·8	33·4	1·4	34·7	1·3	36·6	1·2	36·9	2·0	43·0	2·5	39·9	1·9	34·9	2·0	36·2	1·5	37·6	1·7	9·6	1·3
March, .	34·7	2·4	35·1	1·4	35·5	1·5	38·1	2·4	38·5	2·2	43·0	3·0	42·0	2·5	37.0	2·6	39·5	2·3	39·2	2·3	8·3	1·6
April, .	40·8	3·4	44·2	2·5	40·5	1·7	44·1	2·6	45·2	3·0	47·6	4·2	45·8	3·9	45·7	4·6	43·9	3·1	43·4	2·9	7·1	2·9
May, . .	46·9	4·0	46·4	2·3	48·0	2·4	49·9	2·8	51·5	3·8	54·0	4·0	50·7	3·9	48·8	4·6	49·3	2·6	49·2	3·2	7·6	2·3
June, . .	52·8	3·7	52·2	2·4	51·3	2·2	53·2	3·3	55·4	4·1	58·2	5·0	56·9	4·3	54·8	4·0	54·9	2·8	54·2	3·3	6·9	2·8
July, . .	55·3	4·1	55·4	2·0	53·5	2·1	53·8	3·6	59·5	3·7	60·1	4·5	56·8	3·8	56·5	4·3	55·3	2·7	56·0	3·3	6·6	2·5
August, .	55·7	3·1	53·8	2·2	54·5	2·1	57·8	2·8	59·4	3·1	57·5	2·8	56·2	3·3	57·3	4·2	56·1	2·3	56·1	2·9	5·6	2·1
September, .	47·2	2·8	50·9	1·9	51·9	1·8	52·3	1·8	56·4	3·3	54·4	3·2	53·5	3·1	51·6	3·3	53·2	2·2	52·8	2·8	9·2	1·5
October, .	41·5	2·5	44·8	1·1	45·3	1·7	47·4	1·7	48·0	2·5	49·7	2·8	46·7	2·4	43·9	2·8	44·2	1·3	46·0	2·2	8·2	1·7
November, .	35·1	2·2	39·5	1·3	41·6	1·5	40·4	2·5	44·2	2·1	46·2	2·4	42·7	2·0	38·7	2·0	39·6	1·4	41·7	1·8	11·1	1·2
December, .	34·3	1·5	36·7	1·7	36·6	1·4	34·9	1·7	39·8	1·7	44·6	2·3	39·1	1·9	37·9	1·6	34·4	1·1	38·4	1·7	10·3	1·2
Annual Range, .	22·2	2·6	22·2	1·4	21·0	1·2	24·6	2·4	22·6	2·4	18·0	2·7	17·8	2·4	24·0	3·0	21·7	2·0	18·5	1·6	6·8	1·8
Spring, .	40·9	3·3	42·5	2·2	42·5	1·9	44·7	2·6	46·3	3·1	47·2	3·5	45·3	3·2	42·5	3·6	44·3	2·7	44·0	2·8	6·3	1·7
Summer, .	54·7	3·6	53·7	2·2	52·7	2·1	54·9	3·2	57·9	3·7	58·6	4·1	56·6	3·7	56·2	4·2	55·5	2·6	55·4	2·7	5·9	2·1
Autumn, .	42·3	2·6	43·8	1·4	45·6	1·6	45·3	1·6	48·0	2·5	50·5	2·9	47·9	2·5	44·6	2·7	46·0	1·6	46·8	2·3	8·2	1·5
Winter, .	33·7	1·7	34·7	1·5	34·8	1·3	35·0	1·4	39·1	1·9	43·3	2·4	39·8	1·9	35·3	1·8	35·2	1·3	38·1	1·8	9·6	1·1
Year, . .	43·4	2·9	44·3	2·0	45·4	1·9	44·1	2·2	47·2	2·8	49·1	3·1	47·2	2·7	44·8	3·1	44·9	2·0	46·1	2·5	5·7	1·2
No of Observations, .	308		174		880		196		278		362		1935		311		670		5114			

TABLE XXXIV.

Showing the Mean Relative Humidity with different Winds at Edinburgh on the Mean of Seven years.

SATURATION = 100.

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	Mean.	Difference between the Means.
January, . .	82	84	87	87	84	82	84	80	88	84	8
February, . .	81	85	86	89	83	81	84	80	86	85	9
March, . .	77	86	86	80	82	78	81	78	82	82	9
April, . .	74	80	86	80	78	72	73	77	78	78	12
May, . .	73	84	83	81	75	74	74	70	82	78	14
June, . .	76	83	85	78	75	71	73	75	76	78	14
July, . .	75	87	86	77	79	73	77	73	83	79	14
August, . .	81	85	86	82	82	82	79	74	85	81	12
September, .	80	86	87	87	79	79	80	78	85	81	9
October, . .	81	91	87	88	82	81	83	78	90	85	13
November, .	78	90	89	81	84	83	84	84	88	86	12
December, .	85	85	89	82	86	83	84	87	89	85	7
Annual Range, .	12	11	6	12	11	12	11	17	14	8	11
Spring, . .	75	84	85	81	79	76	77	75	79	78	10
Summer, . .	78	85	85	80	78	75	77	74	84	83	10
Autumn, . .	81	88	88	88	82	80	82	80	89	84	9
Winter, . .	82	84	86	86	85	81	84	83	87	84	6
Year, . .	78	84	86	84	80	79	81	77	85	82	9

Table XXXV.

Showing the Vapour in a Cubic Foot of Air in Grains with Different Winds at Edinburgh on the Mean of Seven years.

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	Mean.
January, .	1·8	1·9	1·9	2·0	2·3	2·5	2·4	1·8	2·1	2·2
February, .	1·9	2·0	2·1	2·2	2·1	2·6	2·4	1·9	2·1	2·1
March, . .	1·8	2·1	2·0	2·1	2·2	2·5	2·5	2·0	2·3	2·3
April, . .	2·1	2·7	2·4	2·7	2·7	2·7	2·6	2·5	2·6	2·5
May, . .	2·7	3·1	3·2	3·1	3·3	3·5	3·1	2·8	3·2	3·1
June, . .	3·4	3·7	3·6	3·5	3·7	3·8	3·9	3·7	3·9	3·8
July, . .	3·7	4·2	3·9	3·6	4·4	4·2	4·0	3·7	4·0	4·0
August, . .	4·1	4·1	4·1	4·4	4·6	4·3	4·0	3·9	4·3	4·1
September, .	2·9	3·6	3·8	3·8	4·0	3·8	3·8	3·4	3·9	3·7
October, .	2·5	3·1	3·0	3·3	3·1	3·3	3·1	2·7	2·9	3·0
November, .	1·9	2·4	2·6	2·4	2·8	3·0	2·7	2·3	2·4	2·6
December, .	2·0	2·1	2·1	2·0	2·5	2·8	2·3	2·3	2·1	2·3
Annual Range,	2·3	2·3	2·2	2·4	2·5	1·8	1·6	2·1	2·2	2·0
Spring, . .	2·2	2·6	2·6	2·7	2·8	2·8	2·7	2·3	2·6	2·6
Summer, .	3·7	4·1	3·9	3·9	4·2	4·3	4·0	3·8	4·1	4·0
Autumn, .	2·5	2·8	3·2	3·0	3·1	3·4	3·1	2·8	3·2	3·1
Winter, . .	1·9	2·0	2·0	2·1	2·3	2·6	2·4	2·0	2·1	2·2
Year, . .	2·5	2·8	2·9	2·8	2·9	3·1	3·0	2·7	2·9	2·9

TABLE XXXVI.

Showing the Departure from the Annual Mean of the Temperature, and Humidity at Edinburgh recorded with different Winds.

TEMPERATURE.

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
	°	°	°	°	°	°	°	°	°
January, . .	*4·8*	*5·0*	*4·8*	*5·1*	**1·1**	**3·8**	**2·1**	*5·0*	*3·2*
February, . .	*3·9*	*4·2*	*2·9*	*1·0*	*0·7*	**5·4**	**2·3**	*2·7*	*1·4*
March, . .	*4·5*	*4·1*	*3·7*	*1·1*	*0·7*	**3·8**	**2·8**	*2·2*	**0·3**
April, . . .	*2·6*	**0·8**	*2·9*	**0·7**	**1·8**	**4·2**	**2·4**	**2·3**	**0·5**
May, . . .	*2·3*	*2·8*	*1·2*	**0·7**	**2·3**	**4·8**	**1·5**	*0·4*	**0·1**
June, . . .	*1·4*	*2·0*	*2·9*	*1·0*	**1·2**	**4·0**	**2·7**	**0·6**	**0·7**
July, . . .	*0·7*	*0·6*	*2·5*	*2·2*	**3·5**	**4·1**	**0·8**	**0·5**	*0·7*
August, . .	*0·4*	*2·3*	*1·6*	**1·7**	**3·3**	**1·4**	**0·1**	**1·2**	*0·0*
September, . .	*5·6*	*1·9*	*0 9*	*0·5*	**3·6**	**1·6**	**0·7**	*1·2*	**0·4**
October, . .	*4·5*	*1·2*	*0·7*	**1·4**	**2·0**	**3·7**	**0·7**	*2·1*	*1·8*
November, . .	*6·6*	*2·2*	*0·1*	*1·3*	**2·5**	**4·5**	**1·0**	*3·0*	*2·1*
December, . .	*4·1*	*1·7*	*1·8*	*3·5*	**1·4**	**6·2**	**0·7**	*0·5*	*4·0*
Spring, . .	*3·1*	*1·5*	*1·5*	**0·7**	**2·3**	**3·2**	**1·3**	*1·5*	**0·3**
Summer, . .	*0·7*	*1·7*	*2·7*	*0·5*	**2·5**	**3·2**	**1·2**	**0·8**	**0·1**
Autumn, . .	*4·5*	*3·0*	*1·2*	*1·5*	**1·2**	**3·7**	**1·1**	*2·2*	*0·8*
Winter, . .	*4·4*	*3·4*	*3·3*	*3·1*	**1·0**	**5·2**	**1·7**	*2·8*	*2·9*
Year, . . .	*2·7*	*1·8*	*0·7*	*2·0*	**1·1**	**3·0**	**1·1**	*1·3*	*1·2*

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XXXVI.—*continued.*

Vapour in Cubic Foot of Air. Tenths of Grains.

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
January, . .	*4*	*3*	*3*	*2*	**1**	**3**	**2**	*4*	*1*
February, . .	*2*	*1*	*0*	**1**	*0*	**5**	**3**	*2*	*0*
March, . .	*5*	*2*	*3*	*2*	*1*	**2**	**2**	*3*	*0*
April, . . .	*4*	**2**	*1*	**2**	**2**	**2**	**1**	*0*	**1**
May, . . .	*4*	*0*	**1**	*0*	**2**	**2**	*0*	*3*	**1**
June, . . .	*4*	*1*	*2*	*3*	*1*	*0*	**1**	*1*	**1**
July, . . .	*3*	**2**	*1*	*4*	**4**	**2**	*0*	*3*	*0*
August, . .	*0*	*0*	*0*	**3**	**5**	**2**	*1*	*2*	**2**
September, . .	*8*	*1*	**1**	**1**	**3**	**1**	**1**	*3*	**2**
October, . .	*5*	**1**	*0*	**3**	**1**	**3**	**1**	*3*	*1*
November, . .	*7*	*2*	*0*	*2*	**2**	**4**	**1**	*3*	*2*
December, . .	*3*	*2*	*2*	*3*	**2**	**5**	*0*	*0*	*2*
Spring, . .	*4*	*0*	*0*	**1**	**2**	**2**	**1**	*3*	*0*
Summer, . .	*3*	**1**	*1*	*1*	**2**	**3**	*0*	*2*	**1**
Autumn, . .	*6*	*3*	**1**	*1*	*0*	**3**	*0*	*3*	**1**
Winter, . .	*3*	*2*	*2*	*1*	**1**	**4**	**2**	*2*	*1*
Year, . . .	*4*	*1*	*0*	*1*	*0*	**2**	**1**	*2*	*0*

NOTE.—The heavy type indicates an excess, and the italic type a defect.

TABLE XXXVI.—*continued.*

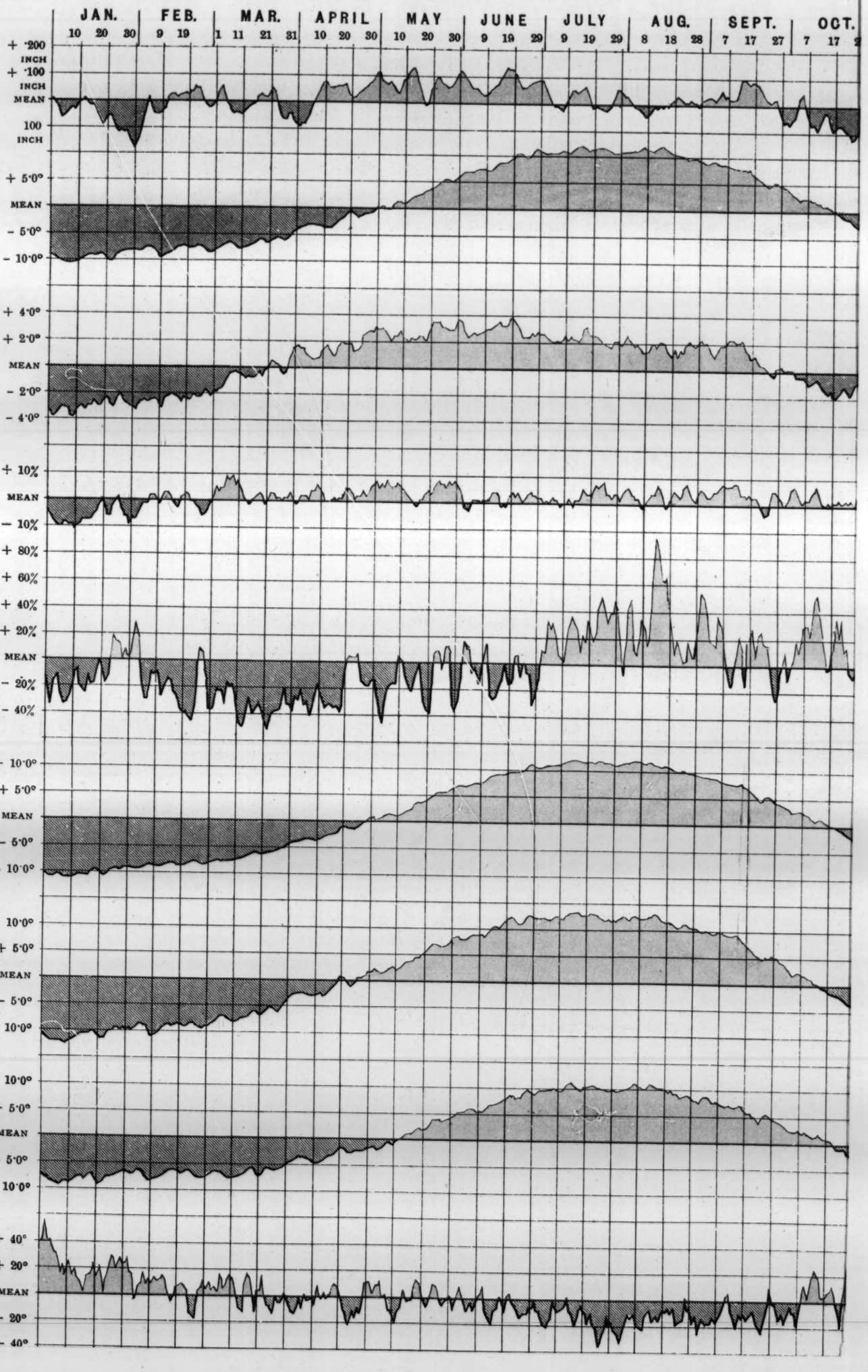
Relative Humidity. Percentage of Excess or Defect.

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
January, . .	*2*	*0*	**3**	**3**	*0*	*2*	*0*	*4*	**5**
February, . .	*4*	*0*	**1**	**4**	*2*	*4*	*1*	*5*	**1**
March, . .	*5*	**4**	**4**	*2*	*0*	*4*	*1*	*4*	*0*
April, . . .	*4*	**2**	**8**	**2**	*0*	*6*	*5*	*1*	*0*
May, . . .	*5*	**6**	**5**	**3**	*3*	*4*	*4*	*8*	**4**
June, . . .	*2*	**5**	**7**	*0*	*3*	*7*	*5*	*3*	*2*
July, . . .	*4*	**8**	**7**	*2*	*0*	*6*	*2*	*6*	**4**
August, . .	*0*	**4**	**5**	**1**	**1**	**1**	*2*	*7*	**4**
September, . .	*1*	**5**	**6**	**6**	*2*	*2*	*1*	*3*	**4**
October, . .	*4*	**6**	**2**	**3**	*3*	*4*	*2*	*7*	**5**
November, . .	*8*	**4**	**3**	*5*	*2*	*3*	*2*	*2*	**2**
December, . .	*0*	*0*	**4**	*3*	**1**	*2*	*1*	**2**	**4**
Spring, . .	*3*	**6**	**7**	**3**	**1**	*2*	*1*	*3*	**1**
Summer, . .	*5*	**2**	**2**	*3*	*5*	*8*	*6*	*9*	**1**
Autumn, . .	*3*	**4**	**4**	**4**	*2*	*4*	*2*	*4*	**5**
Winter, . .	*2*	*0*	**2**	**2**	**1**	*3*	*0*	*1*	**3**
Year, . . .	*4*	**2**	**4**	**2**	*2*	*3*	*1*	*5*	**3**

NOTE.—The heavy type indicates an excess, and the italic type a defect.

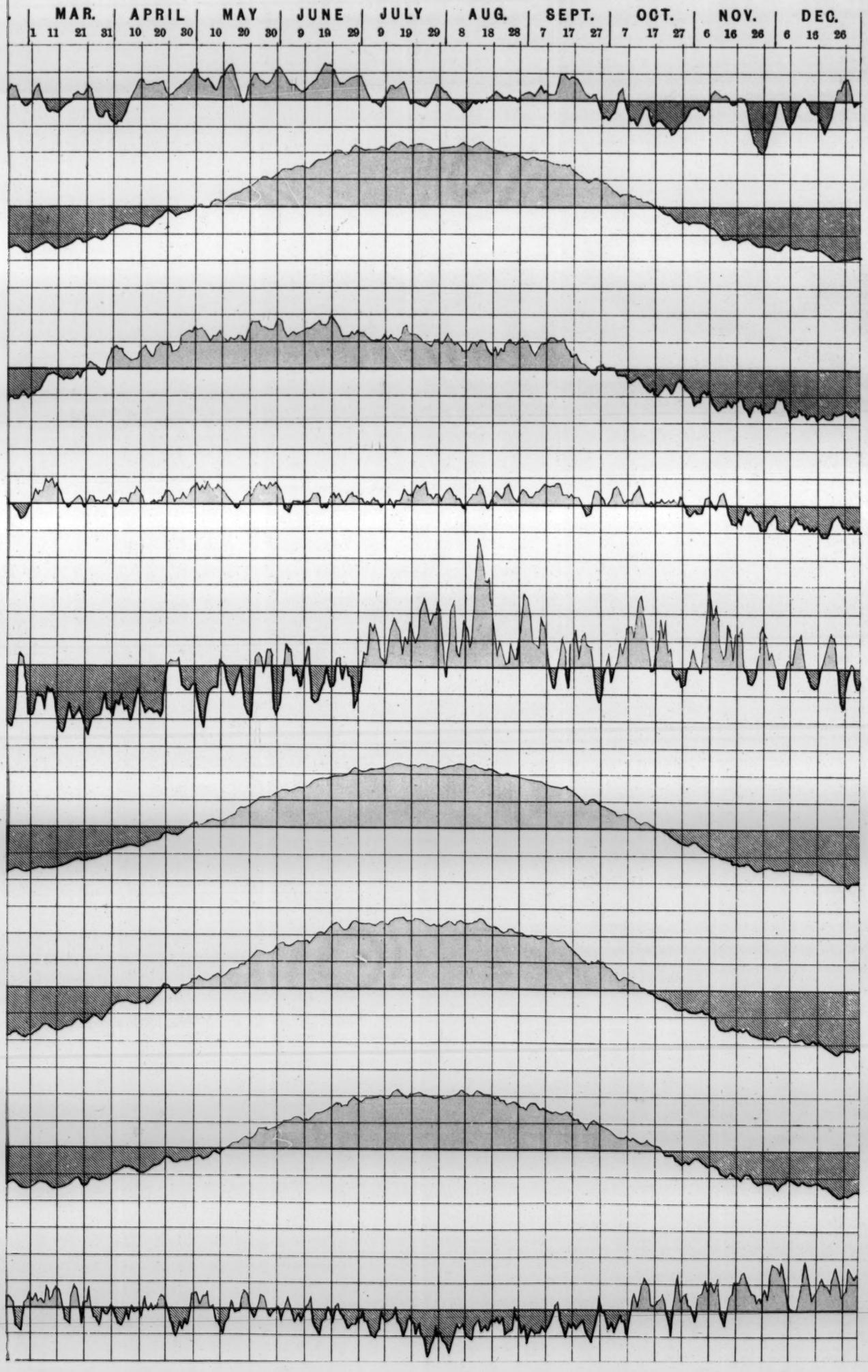
PLATE I.— SHOWING THE DEPARTURE FROM THE ANNUAL MEAN OF THE DAILY METEOROLOGICAL VALUES

NOTE.—THE RED INDICATES AN EXCESS AND THE BLUE A DEFECT.

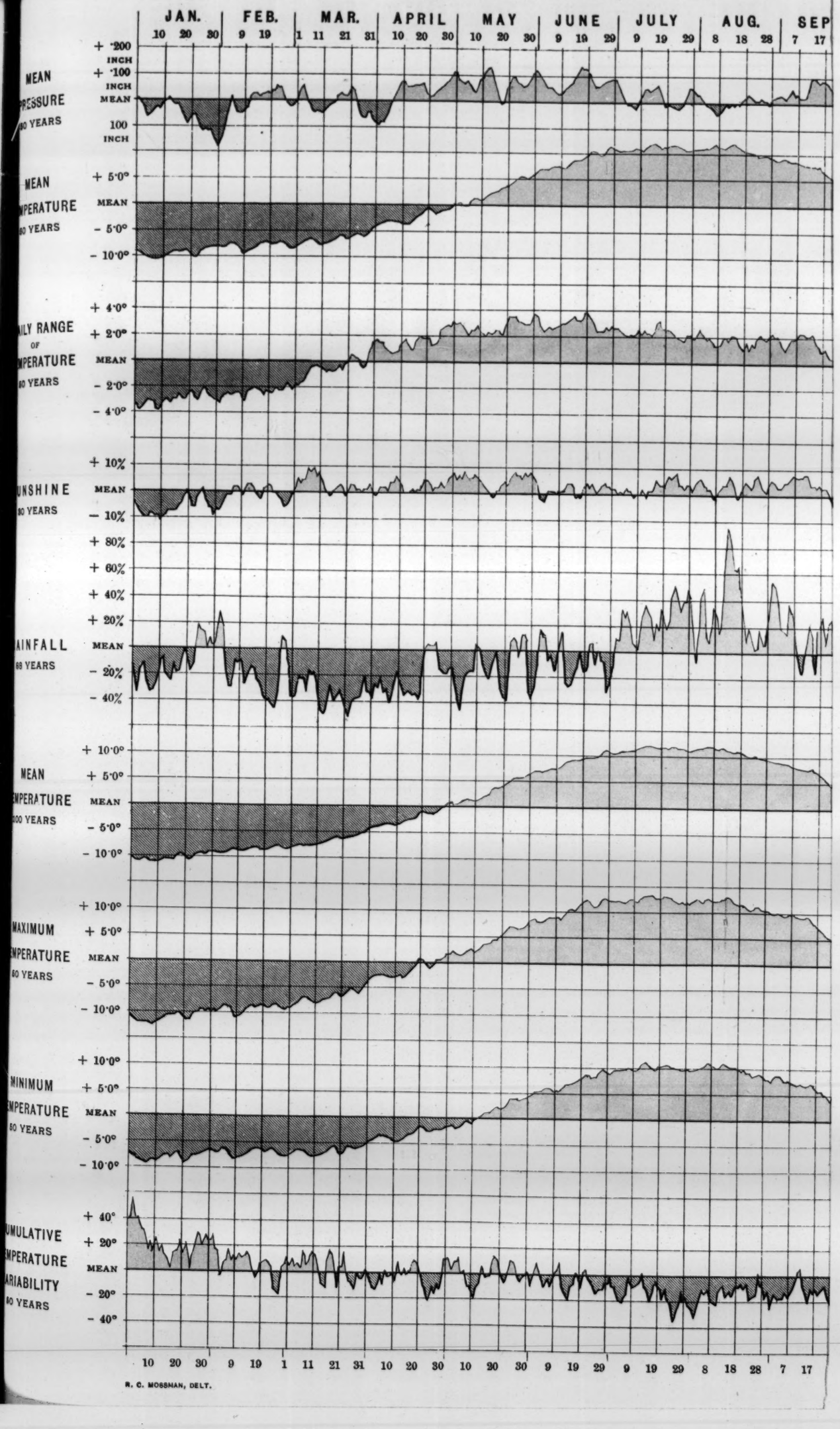


PARTURE FROM THE ANNUAL MEAN OF THE DAILY METEOROLOGICAL VALUES AT EDINBURGH.

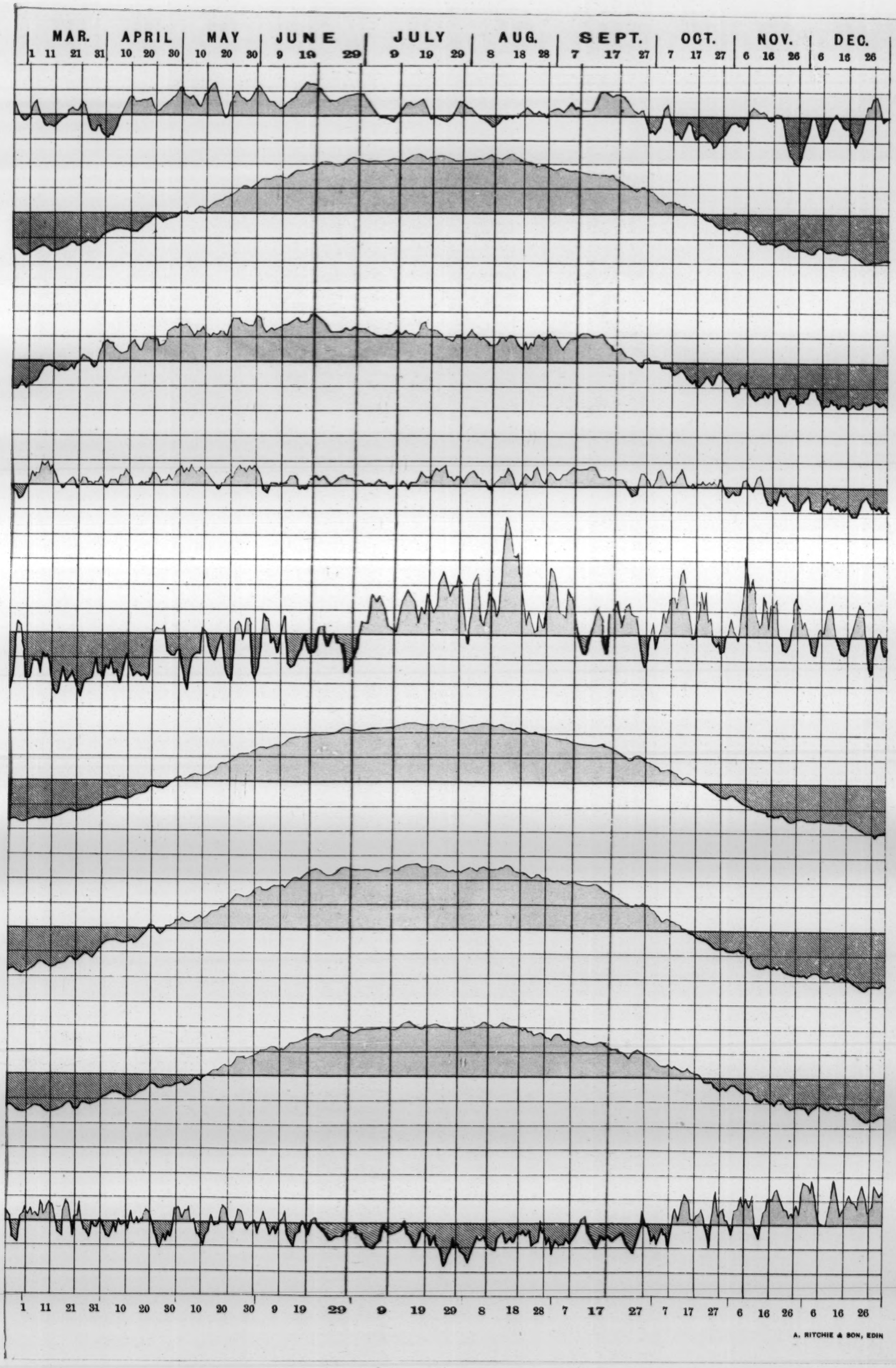
NOTE.—THE RED INDICATES AN EXCESS AND THE BLUE A DEFECT.



NOTE.—THE RED INDICATES AN EXCESS AND THE BLUE A DEFECT.



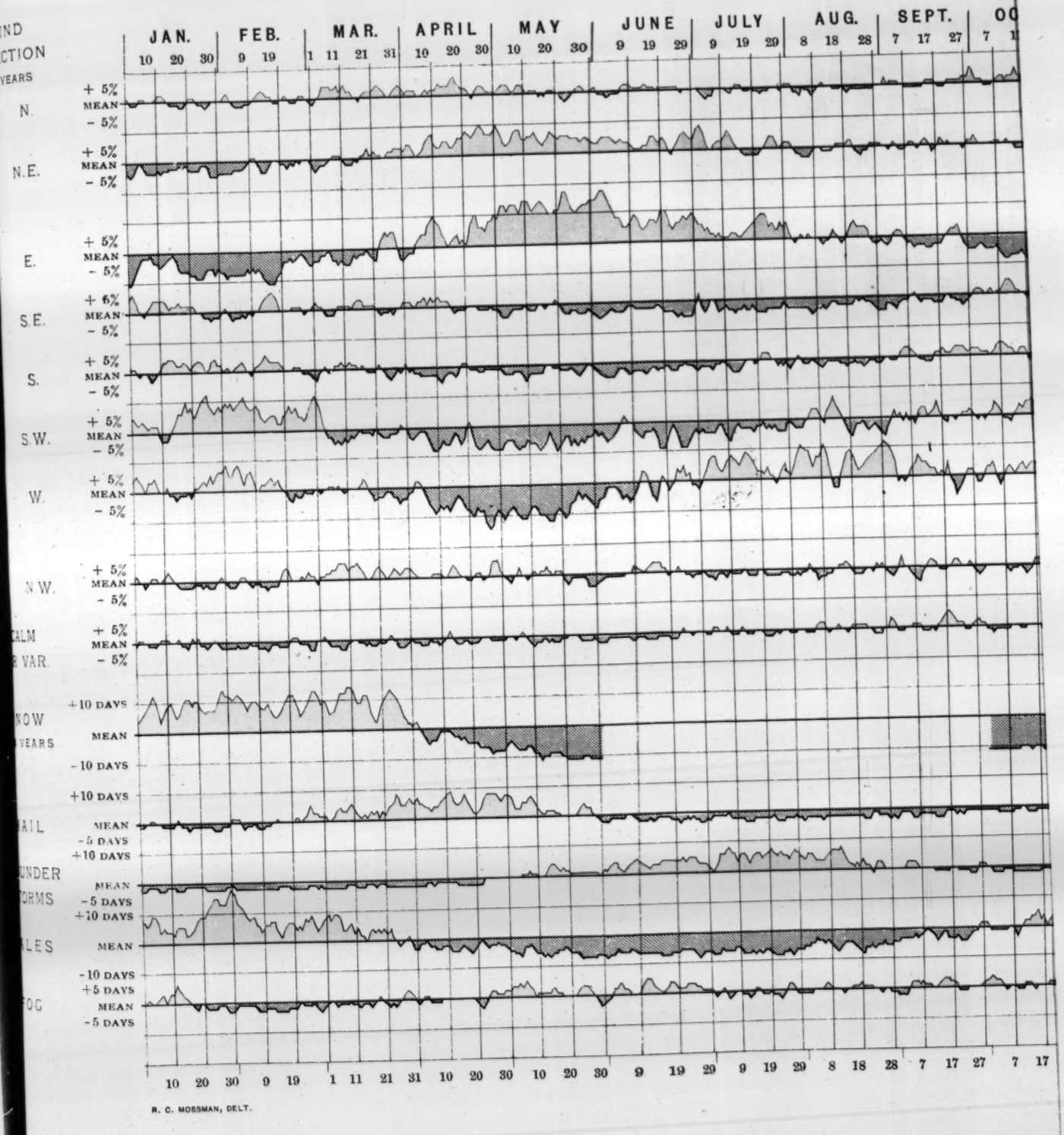
R. C. MOSSMAN, DELT.



A. RITCHIE & SON, EDIN

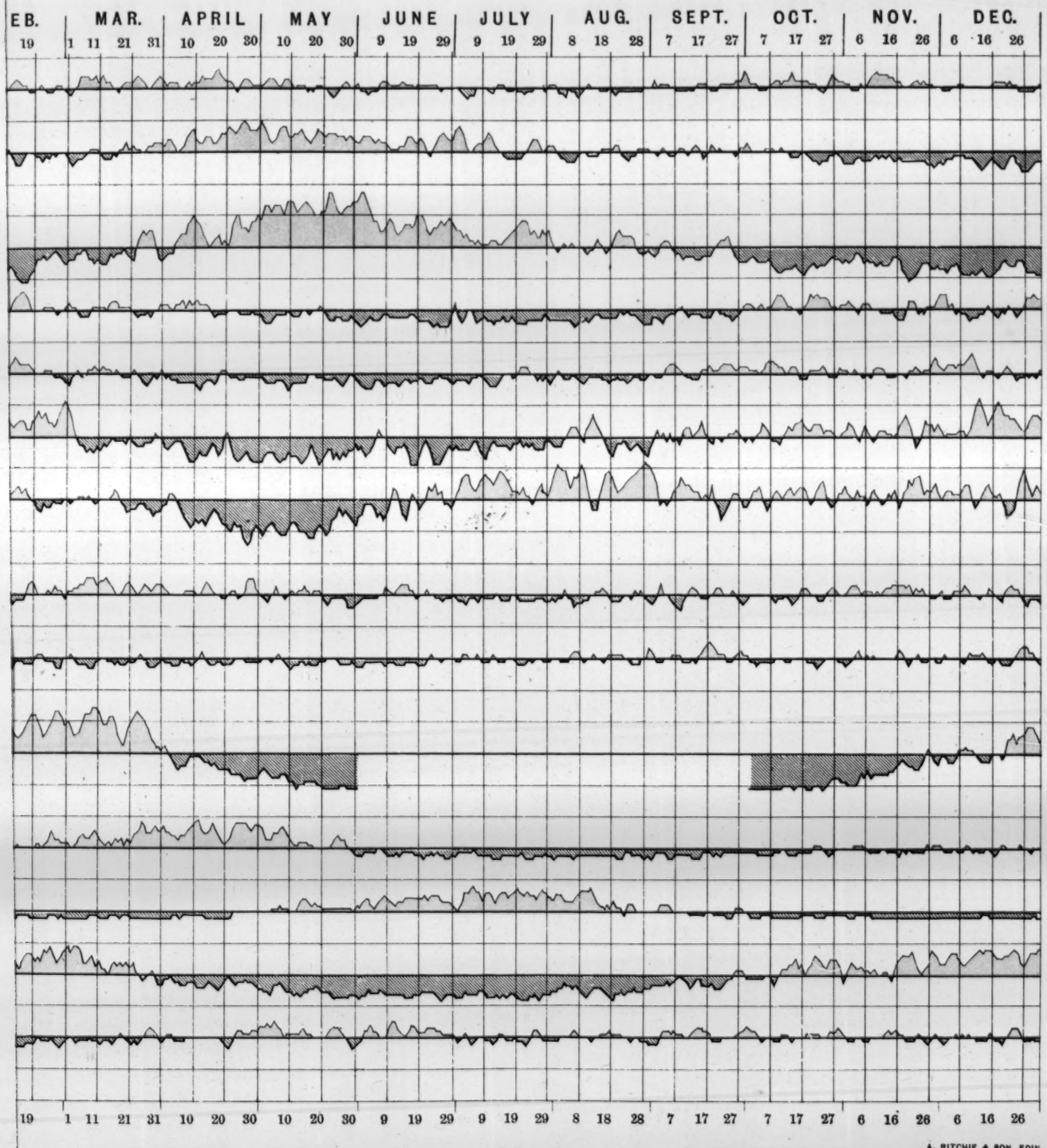
PLATE II.— SHOWING THE DEPARTURE FROM THE ANNUAL MEAN OF THE DAILY METEOROLOGICAL VA

NOTE.—THE RED INDICATES AN EXCESS AND THE BLUE A DEFECT.



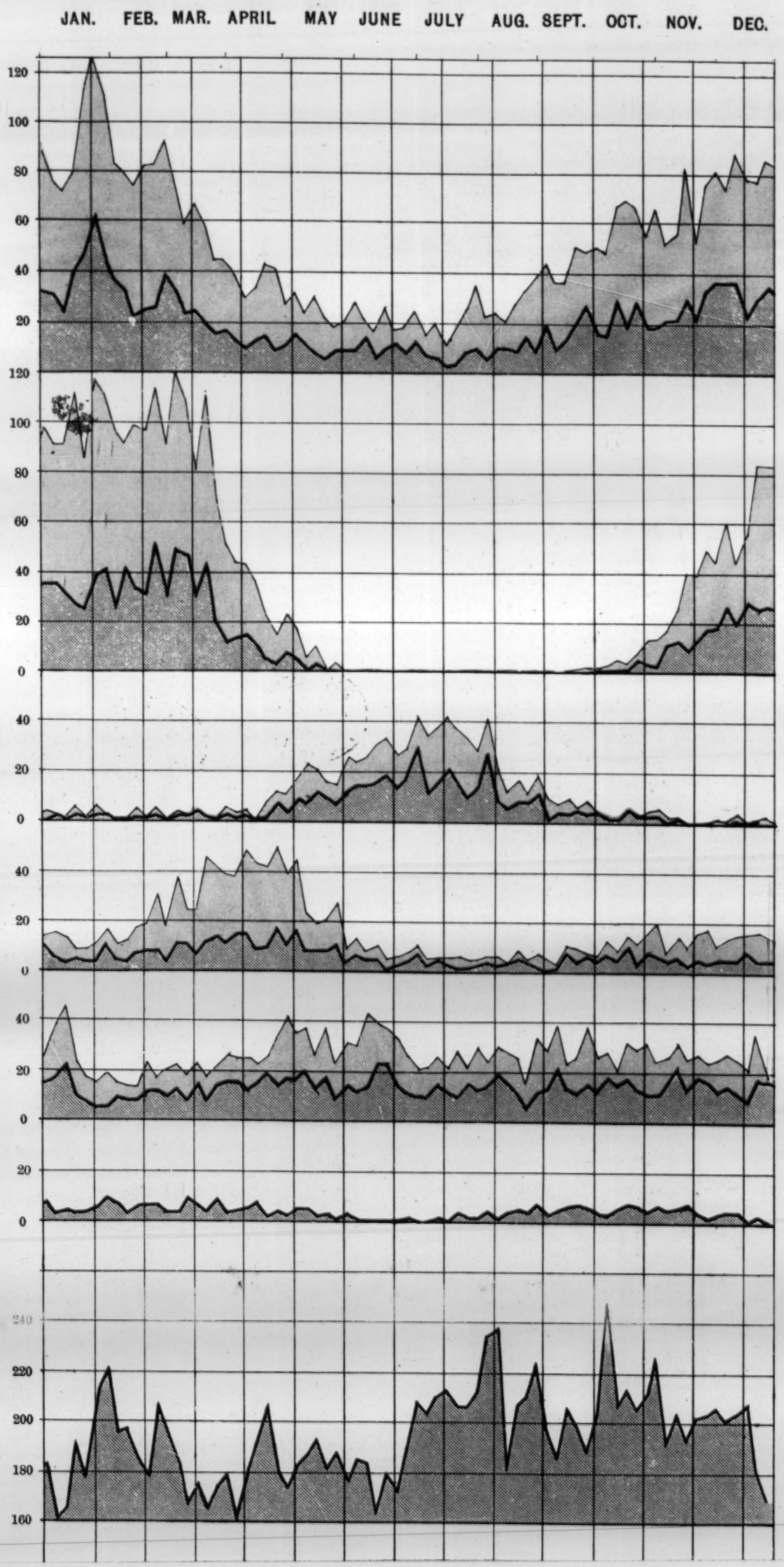
Departure from the Annual Mean of the Daily Meteorological Values at Edinburgh.

Note.—The Red indicates an Excess and the Blue a Defect.



A. RITCHIE & SON, EDIN.

PLATE III.— SHOWING THE FIVE-DAY TOTALS OF THE NON-INSTRUMENTAL PHENOMENA AT EDINBURGH.



XXI.—*On the Curves of Magnetisation for Films of Iron, Cobalt, and Nickel.*

By Dr J. C. Beattie. (With a Plate.)

(Read 6th July 1896.)

§ 1. *Introduction.*—By films of iron, nickel, and cobalt are here meant electrolytic deposits of these metals on platinised glass. The magnetic properties of such films are interesting in various ways. For example, when they are longitudinally magnetised, we have the case of a magnet where the ratio of length to breadth is very great, and where, consequently, the demagnetising force is very small, *e.g.*, with a film of a 5000th part of a millimetre in thickness, and 5 mms. in length, we have a ratio in length to thickness of 25,000 : 1 ; at the same time the film is so small that it can be tested in very high uniform fields.

We have here, perhaps, the most favourable circumstances in which to investigate whether or not the magnetisation reaches a maximum in the paramagnetic metals. The conclusions to be drawn from the existence of such a maximum have been shown by Maxwell. Unfortunately, the direct determination of the magnetisation in these films presents great difficulty. Could it be shown that their variation of resistance for steady currents in a steady magnetic field was proportional to the magnetisation, we would then have a comparatively easy method to determine the latter. This variation for transversal magnetisation can be investigated by means of the Hall effect ; for longitudinal magnetisation, however, we get no help from this nor from Kerr's phenomenon. I have therefore tried, for this case, to determine the magnetisation directly.

§ 2. *Time of vibration of a magnetic film in a steady magnetic field.*—Consider an ellipsoid of iron, say, whose susceptibility κ for a given strength of magnetic field is the same in all directions. Let this ellipsoid be brought into a steady magnetic field whose components are α, β, γ, in three mutually perpendicular directions. It will take a position such that its longest axis will be parallel to the direction of the resultant impressed magnetic force ; it will be uniformly magnetised, and the components of magnetisation will be A, B, C, given by

$$A = \frac{(\mu_1 - 1)\alpha}{4\pi + L(\mu_1 - 1)}$$

$$B = \frac{(\mu_2 - 1)\beta}{4\pi + M(\mu_2 - 1)}$$

$$C = \frac{(\mu_3 - 1)\gamma}{4\pi + N(\mu_3 - 1)}$$

where μ_1 μ_2 μ_3 are the permeabilities for the forces α β γ respectively, and L, M, N are constants depending on the form of the body.

Let the field be of uniform intensity **H**, and suppose the ellipsoid to be in its position of equilibrium. Draw the x-axis parallel to that line of the body which sets itself parallel to the direction of the field; let the y- and z-axes be perpendicular to it and to each other, so that they form a right-handed system fixed in space.

Next let the ellipsoid suffer a rotation θ about its y-axis: it will then be acted on by a couple Γ.

$$\Gamma = \text{Vol of ellipsoid} \left\{ H^2 \sin\theta \cos\theta \left[\frac{\mu_1 - 1}{4\pi + L(\mu_1 - 1)} - \frac{(\mu_3 - 1)}{4\pi + N(\mu_3 - 1)} \right] \right\}$$

But we may look on our film as a very flat ellipsoid of revolution with $a = b$ and c extremely small; for it

$$L = \pi^2 \frac{c}{a} = \text{a very small quantity.}$$

$$N = 4\pi$$

so that for the film we may write

$$\Gamma = \text{Vol of film.} \quad H^2 \cos\theta \sin\theta \left\{ \frac{\mu_1 - 1}{4\pi} - \frac{\mu_3 - 1}{4\pi + 4\pi(\mu_3 - 1)} \right\}$$

$$\Gamma = \text{Vol of film.} \quad H^2 \cos\theta \sin\theta \left\{ \kappa_1 - \frac{\kappa_3}{1 + 4\pi\kappa_3} \right\}$$

$$= \text{Vol of film.} \quad \kappa_1 H. \quad H \cos\theta \sin\theta \left\{ 1 - \frac{\kappa_3}{\kappa_1 \mu_3} \right\}$$

And the equation of motion of the film in a magnetic field is

$$K\ddot{\theta} + MH \cos\theta \sin\theta \left\{ 1 - \frac{\kappa_3}{\kappa_1 \mu_3} \right\} = 0$$

where K is the moment of inertia of the rotating body, and M its magnetic moment.

When θ is small the period of vibration, τ, is

$$\tau = 2\pi \sqrt{\frac{K}{MH \left\{ 1 - \frac{\kappa_3}{\kappa_1 \mu_3} \right\}}}$$

Which we may write

$$MH \left\{ 1 - \frac{\kappa_3}{\kappa_1 \mu_3} \right\} = \frac{4\pi^2 K}{\tau^2}$$

That is, M is given by the equation

$$M \left\{ 1 - \frac{\kappa_3}{\kappa_1 \mu_3} \right\} = \frac{4\pi^2 K}{\tau^2 H} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If $\frac{\kappa_3}{\kappa_1\mu_3}$ is small compared with unity we obtain the ordinary formula

$$M=\frac{4\pi^2K}{\tau^2H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and as $M = I \times \text{vol}$ we can get a quantity proportional to the magnetisation of the film.

At a certain field strength the formula (1) will give for M a maximum value, after which its value will decrease: we may explain this, in a general way, by saying that two magnetic forces act on the film: the one calls forth a longitudinal magnetisation, the other a transversal. With low fields the first has the upper hand: the influence of the second increases more rapidly however, and as it works against the first it produces an apparent decrease in the magnetisation.

§ 3. *Application of Equation* (1).—We have next to consider for what field strengths the equation (1) can be used in its simplified form (2), or, in other words, when $\frac{\kappa_3}{\kappa_1\mu_3}$ can be neglected in comparison with unity. κ_1 is the susceptibility corresponding to that field strength which is concerned in the longitudinal magnetisation, and which is approximately equal to the strength of the impressed field with no film present. κ_3 and μ_3 are the susceptibility and permeability respectively due to the field producing the transverse magnetisation; its value may be taken to be a 20th (say) of the other; that would correspond to a rotation of 2 or 3 degrees. Let us assume that the value of the susceptibility in a film is the same as in the annealed form of the metal; we can then take values of κ_1 and κ_3 from the results obtained by previous experiments, and in this way calculate $\frac{\kappa_3}{\kappa_1\mu_3}$. This is the correction which has to be subtracted from the result to allow for the effect of the transverse magnetic force.

I have applied this correction to Du Bois's results as given by Ewing—*Magnetic Induction*, p. 158—κ_1 is taken from them; κ_3 is taken from Ewing's book, p. 74 for iron; p. 86, nickel; p. 89, cobalt.

For iron and cobalt the error introduced by putting $\frac{\kappa_3}{\kappa_1\mu_3}$ equal zero is for the lower fields not appreciable, and for the more moderate values rises to 3 or 4 per cent.,—a difference which, in the ordinary method of representing the magnetisation by a curve, would not be observable. For nickel, however, this is no longer true: the curve obtained by this method differs greatly from the correct one.

§ 4. *Experimental Arrangement.*—The films were deposited electrolytically on platinised glass from solutions of iron oxydul ammoniak, cobalt oxydul, and nickel oxydul ammoniak respectively. Portions which appeared most regular to the eye were cut off in rectangles of 15 mms. length and 10 mms. breadth. The plate thus obtained

was suspended by a fibre; to ballast it, and at the same time to have a pointer which would enable the time of vibration to be more easily obtained, a rectangular strip of lead was attached to it with its length perpendicular to the surface of the plate and out of the field. This lead swung just over a graduated circle.

The moment of inertia K of the lead, the glass, and the connecting parts was determined separately; the time of vibration τ with the field on was determined by means of a stop watch.

To create the uniform field, a Ruhmkorff electro-magnet was used, with poles 50 mms. in diameter, and about 15 mms. apart. The field strength K was measured by Verdet's method, using the rotation of red light in glass.

Thus in the equation

$$M\left(1-\frac{\kappa_3}{\mu_3\kappa_1}\right)=\frac{4\pi^2K}{H\tau^2}$$

if we can neglect $\frac{\kappa_3}{\mu_3\kappa_1}$, everything is known but M. M divided by the volume of the film would give the magnetisation in absolute measure; the thickness of the plates, however, was not measured; the order of magnitude was known, and this gave for the magnetisation (greatest) results which were of the same order of magnitude as those obtained by other methods.

To hinder as much as possible the creation of induction currents, the films were scratched with a diamond parallel to the direction of the field.

It was found that the platinised glass alone, without film, had a definite period of vibration due to a definite field strength; this was observed after the film had been taken off by acid, and was applied as correction to what had been obtained for the glass with the magnetic film on it.

The time of vibration was observed for different field strengths by beginning with the lowest, and rising to the highest. Then the electro-magnet and the film were demagnetised, and the same series repeated, and so on for the other series.

§ 5. *Results with Iron Films.*—Four different forms were used: two, I. and II., so thick as to be opaque; and two, III. and IV., quite transparent.

PLATE I.—15 × 8 mms.

Field.	τ in $\frac{1}{4}''$.	10,000 M.
260	40·5	1218
360	31·2	1503
560	24·1	1583
740	19·6	1768
970	16·96	1798
1270	14·8	1804
1750	12·6	1810
2550	10·22	1883

PLATE II.—16 × 7 mms.

Field.	τ in $\frac{1}{4}''$.	10,000 M.
260	45·5	1022
295	39·6	1031
480	30·55	1087
595	26·0	1116
740	23·52	1146
970	20·85	1107
1270	18·25	1031

PLATE III.—18 × 7 mms.

Field.	τ in $\frac{1}{4}''$.	100,000 M.
260	84·0	384
360	65·0	468
450	56·2	561
560	52·4	600
740	45·5	616
970	41·5	587
1270	35·87	616
1750	31·75	634
2550	27·0	624

In I. and II. the correction due to the glass without film was so small as to be negligeable; in III. that was no longer the case, and the M given in the third column is not that obtained from the τ in column two, but that minus the correction due to the glass itself.

In the appended graphs are given side by side the magnetisation curve as given by the above numbers and as plotted from DU BOIS's results,—EWING's *Magnetic Induction*, page 158. In II. the curve has the same form exactly as that from the ellipsoid, and from this film we may conclude that the magnetic properties of the film are the same as those for annealed iron. In the other three curves, however, there is not such a good agreement with those from annealed iron; in weaker fields particularly is this disagreement very great, while theoretically we should have here little deviation; in each case the curve differs in the same way, and by as much as 30 or 40 %. This difference cannot arise from the correction due to the glass, that in Plate I., at any rate, affects only the third significant figure; nor is it likely to arise from an error in the observations, as these were repeated three different times, and each time gave values of τ agreeing to within $\frac{1}{2}$ to 1 per cent.; again, it cannot be brought about by the form of the plate, as in two of the plates we have a ratio of length to breadth of about 8000 : 1, in the other two of about 100,000 : 1.

We must conclude that the magnetic properties of these three plates I., III., IV. differ from these of annealed iron; the curves have a greater resemblance to the corresponding ones of hardened iron, where the susceptibility is less.

§ 6. *Cobalt.*—Five plates prepared from three different deposits were used. The results for three of these are given.

PLATE V.—23 × 9·4 mms.

Field.	τ in $\frac{1}{4}''$.	10,000 M.
226	33·3	627
350	25·5	645
400	23·65	667
450	21·57	715
515	19·75	757
625	17·85	766
750	16·12	815
925	14·27	825
1250	12·37	820

PLATE VI.

Field.	τ [First Time Used.]	τ [Second Time.]	τ [Third Time.]	10,000 M. First Time.	10,000 M. Second Time.
210	60·0	54·0	53·5	218	272
283	49·75	46·2	46·25	235	273
353	43·0	40·5	40·2	254	288
396	40·3	38·0	38·2	256	286
450	36·25	35·0	35·66	278	293
510	33·15	32·65	32·95	292	299
630	30·75	30·4	...	278	
720	27·7	27·25	...	302	
920	24·55	24·7	...	296	
1230	20·85	21·5	...	302	

PLATE VII.—10 × 7 mms.

Field.	τ in $\frac{1}{4}''$.	100,000 M.
243	68·10	918
310	58·25	987
480	47·25	1038
560	42·9	1145
670	40·4	1121
800	35·5	1289
970	32·22	1234
1270	27·88	1237
1750	24·47	1214
2555	20·7	1197

Here it will be noticed that the agreement between the general outline of the curves with those from Du Bois's results is much better than in the case of iron, and we are justified in drawing the conclusion that the permeability of films of electrolytically deposited cobalt is the same as in those specimens of cobalt used in ellipsoidal form by the above experimenter. In Plate VI. the curve derived from the first series of observations differs in the lower fields from those obtained from the second and third series. The same result was obtained with another plate (VIII.); it, when first used, gave a smaller value of the magnetisation than in the second instance after it had been demagnetised and the experiments repeated.

The other two Plates, V. and VII., had been magnetised and demagnetised several times before they were used; the curves in their case correspond to the curve given by the second and third series in Plate VI.

Of the three Plates, V. was the thickest, almost opaque; the other two were quite transparent.

§ 7. *Nickel.*—Several specimens of this metal were used. The results for two of the plates are here given.

PLATE VIII.

Field.	τ in $\frac{1}{4}''$ for film and glass.	τ in $\frac{1}{4}''$ for glass alone.	10,000 M.
210	47·47	99·0	269
283	40·97	89·0	274
352	36·00	80·0	289
396	33·3	77·5	306
450	30·75	74·5	321
510	27·85	70·0	349
630	25·1	65·0	350
720	22·3	62·0	400
920	20·0	59·0	398
1230	18·15	55·0	361

PLATE IX.—17 × 8 mms.

Field.	τ in $\frac{1}{4}''$ for film and glass.	τ in $\frac{1}{4}''$ for glass alone.	10,000 M.
210	60·87	102·0	135
283	50·95	90·0	153
352	45·27	82·0	155
396	41·17	76·0	173
450	37·92	73·0	186
510	34·5	68·0	201
630	31·42	66·0	204
720	28·56	61·5	220
920	24·75	57·5	239
1230	22·40	54·0	221

For nickel, the method of vibration has little or no value; with very moderate fields the effect of the transversal magnetisation makes a difference of almost 10 per cent., and with a 1200 c.g.s. field the result obtained—always assuming that nickel films have the same magnetic properties as annealed nickel—differs from the correct result by more than 20 per cent. Again, the correction due to the glass with no nickel on it which has to be applied is for the lowest field very large, as much as 25 per cent. in some cases.

On comparing the curves for the films with that for the ellipsoid, it will be seen that here again, with the lowest fields, there is a very perceptible difference. The film curves have a greater similarity to those of hardened nickel than with the annealed variation. That this is not due to an experimental error can be seen from a comparison of the curves of magnetisation obtained by assuming the variation of electric resistance of the film considered in a magnetic field to be proportional to the magnetisation squared; this latter curve shows exactly the same rounded form.

The results given for Plates IX. and X. were obtained after the plates had been used many times; and in the final series of experiments the periods of vibration did not differ from those obtained after everything had been demagnetised and another series made. With other plates, however, where the period of vibration for the film was determined before it had been exposed to any other magnetic influence, the first series gave for the lower fields a much larger period of vibration; that is, a much smaller magnetisation,—in some instances a difference of 50 per cent.

§ 8. *Conclusions.*—We cannot draw any conclusions other than the most general ones from the above experiments; a direct determination of the magnetisation might have been made by measuring the thickness of the films; however, such measurements cannot be made more exactly than to within 5 or 10 per cent., and by the above method we have already an error of 2 or 3 per cent. in iron and cobalt, and a much greater error in nickel; from such a combination of inexact results we cannot hope for anything definite.

We may, however, quite generally say—

(1) That in the form of transparent films, the permeabilities of the magnetic metals and the limiting values of the magnetisation bear the same relation to each other as in the ordinary non-transparent specimens of the material usually experimented with.

(2) That in nickel and iron the form of the film magnetisation curve resembles more that for the hardened form than the annealed.

(3) That in cobalt and nickel the magnetisation curve, as determined by the above method, differs as it is determined from an unused, that is, not before magnetised—or used, previously magnetised—film; that is, we have hysteresis in these transparent films.

In conclusion, I have to thank Profs. Warburg and Rubens of the Physical Institute, Berlin, for the interest they took in my work, and for their kindness in placing the apparatus of the Institute at my disposal.

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CURVES OF MAGNETISATION FOR IRON, COBALT, AND NICKEL FILMS.

PLATE I.

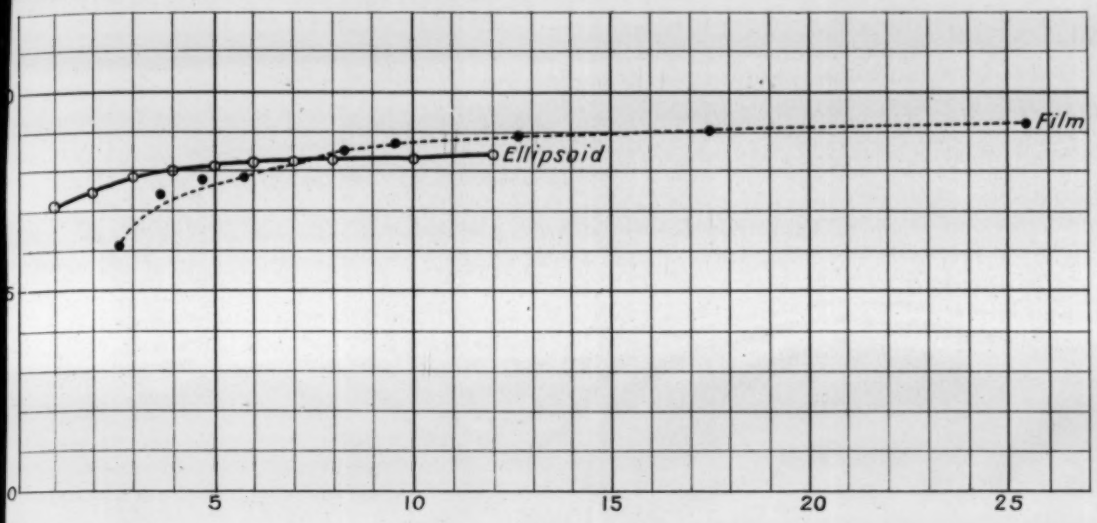


PLATE II.

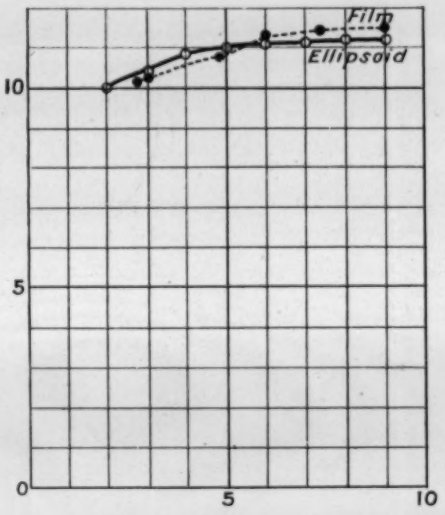


PLATE III.

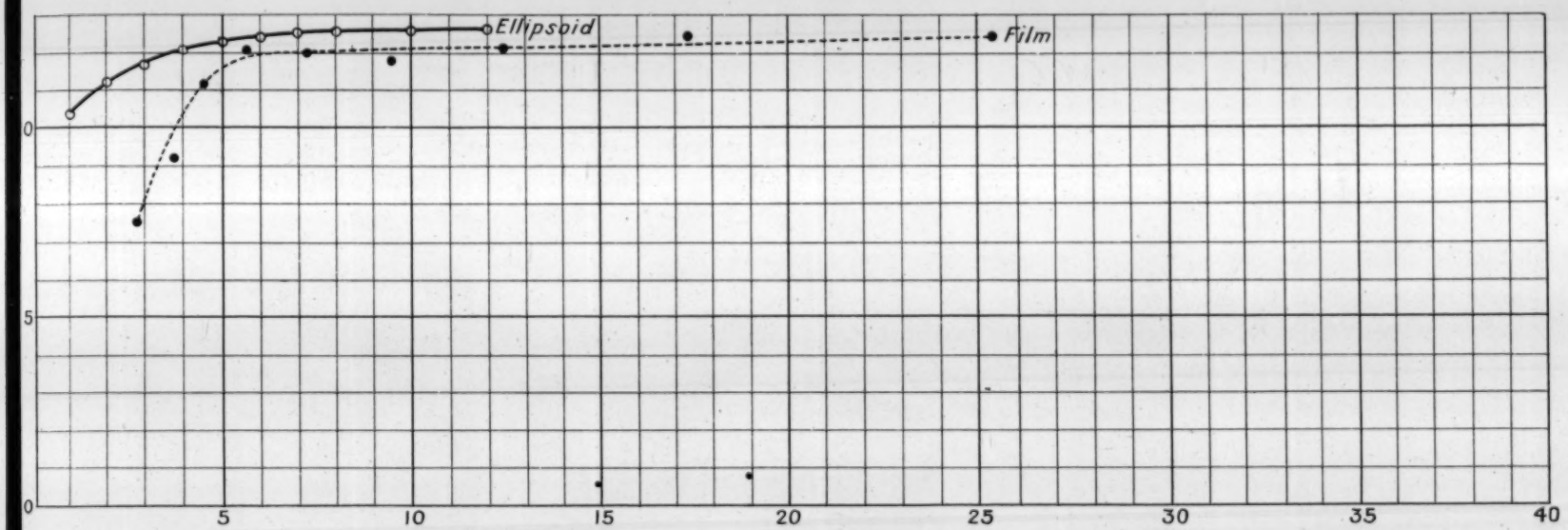


PLATE V

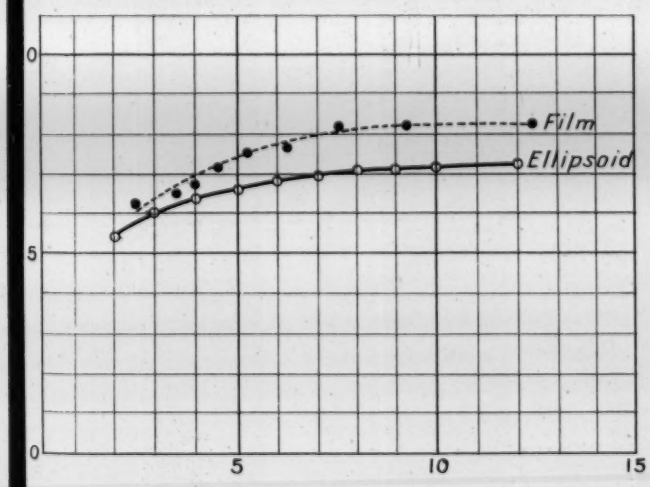


PLATE VI.

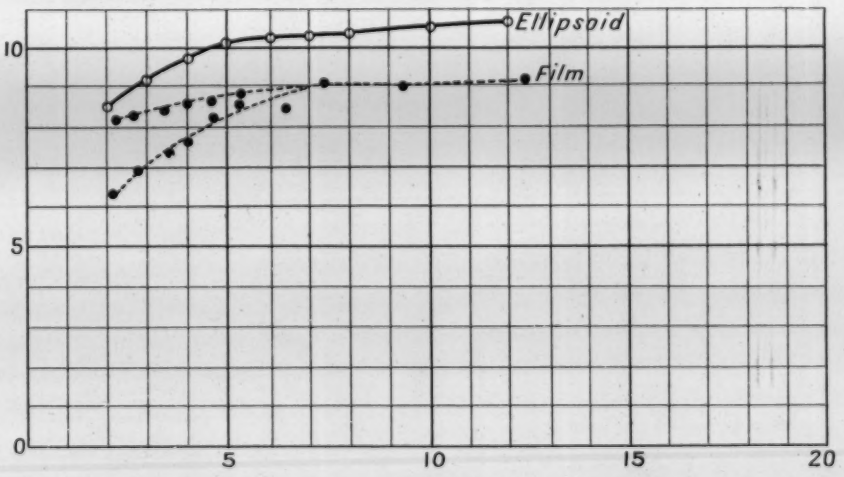


PLATE VII.

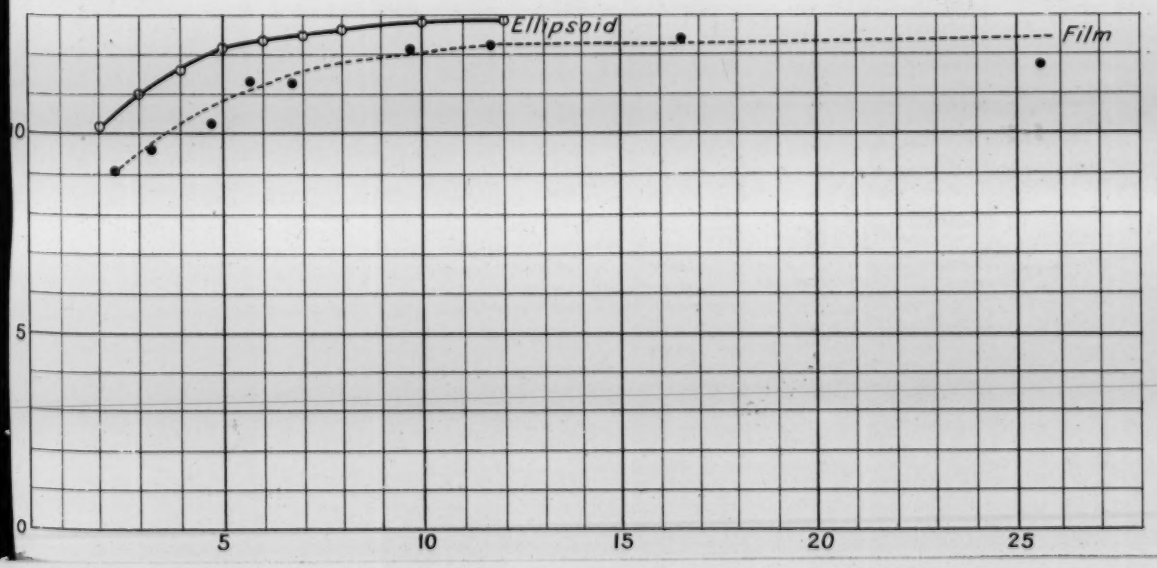


PLATE IX.

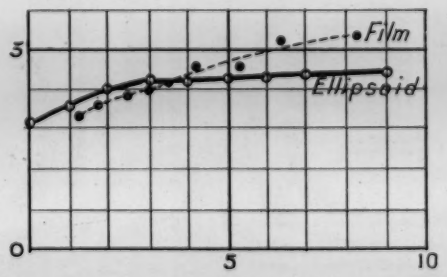


PLATE X.

XXII.—*Observations on the Phonograph.* By John G. M'Kendrick, M.D., Professor of Physiology in the University of Glasgow. (With Two Plates.)

(Read 17th February 1896.)

Introduction.

1. Since I had the honour of showing the phonograph to the Royal Society of Edinburgh, at a special meeting in November 1894, the instrument has occupied a good deal of my time and attention, and I now venture to give the general results of the investigation.

2. The instrument chiefly studied has been the machine used in this country known as the "Commercial Phonograph." Any records taken by myself have been obtained with the ordinary apparatus forming part of the "commercial" speaker arm, but I have always reproduced these with the aid of the so-called "musical" arm. The commercial machine, or, to give it a better name, the English model, is so geared that the wax cylinder, $6\frac{7}{8}$ inch (197 mm.) in circumference, makes two revolutions in one second, while the spiral grooves described on the cylinder are $\frac{1}{200}$ inch ($\frac{1}{8}$ mm.) apart. A spiral line about 136 yards in length may be described on the cylinder, and the recording or reproducing point travels over this distance in about six minutes.

3. I have also used the American model, which resembles in all essential particulars the one just described, except that the grooves on the cylinder are $\frac{1}{100}$ inch ($\frac{1}{4}$ mm.) instead of $\frac{1}{200}$ ($\frac{1}{8}$ mm.).

I. Resonators for Increasing Volume of Tone.

4. By using conical resonators of considerable size, made of thin block tin, the tone of the phonograph can be increased in volume, so that the sounds become audible and agreeable in a large room. The use of resonators is common in America, but these are of comparatively small dimensions, and, while they do not yield the volume of tone obtained by those of greater size, they do not get rid of the upper partials that give the peculiar character to the sounds emitted by the glass disk of the phonograph. To this I attribute the preference often given by phonograph operators to the method of conveying the sounds directly to the ears by flexible tubes. The latter plan no doubt gives volume of tone and also faithfulness of quality, as it carries the sound to within a few millimetres of the drum head, but the advantage is more than compensated by the discomfort of the proceeding, and by the jarring friction noises that are obtruded with painful distinctness. The largest resonator I use is of conical form, about 8 feet

11 inches in length, with a diameter at its wide end of 3 feet, and at its narrow end of $\frac{3}{4}$ inch. The best results have been obtained with tin resonators. One large wooden resonator, shaped like a four-sided pyramid, formed of wood used for making wooden organ pipes, 10 feet $7\frac{1}{2}$ inches in length, each side being 3 feet in length at the base and $\frac{3}{4}$ inches at the apex, gave excellent results as regards volume and quality, but it had a curious effect of damping or muffling the tones. Resonators of vulcanite, papier-maché were unsatisfactory. A conical resonator about 3 feet in length, 4 inches in diameter at the wide end, and $\frac{3}{4}$ inch at the narrow end, made of thin aluminium, gave a remarkably clear ringing tone. Large resonators appear not only to give roundness and volume to the tone, but also to quench many of the upper partials which cause the hissing noises heard near the glass disk of the phonograph. In this way quality of tone is improved. I have endeavoured to modify the form of the resonators in various ways in the hope of altering the quality of the tone, but without success.

The resonators I employ have the following measurements :—

No.	Material.	Length.	Diameter at wide end.	Diameter at narrow end.	Name.
1.	Tin, . . .	8 feet 11 inches	3 feet	$\frac{3}{4}$ inch	Great resonator.
2.	Tin, . . .	6 feet 6 inches	18 inches	$\frac{3}{4}$ inch	Small resonator.
3.	Wood $\frac{5}{8}$ inch thick,	10 feet $7\frac{1}{2}$ inches	3 feet	$\frac{3}{4}$ inch	Wooden.
4.	Brass, . . .	3 feet $11\frac{3}{4}$ inches	$9\frac{3}{4}$ inches	$\frac{3}{4}$ inch	Brass.
5.	Aluminium, . .	3 feet 1 inch	$7\frac{3}{4}$ inches	$\frac{3}{4}$ inch	Aluminium.

5. I have not been able to find any clear explanation of the mode of action of conical resonators. Experience has shown that a cone is the best form both for a receiver by which sound waves are transmitted to the phonograph disk, and for strengthening the tone in reproduction. When used as a receiver in taking records, the cone should be long and narrow, and, on the other hand, in reproduction, the best results are obtained by increasing the length, and by increasing the diameter at the broad end. Lord RAYLEIGH states that if the diameter of the large open end be small in comparison with the wave length, the waves on arrival suffer reflexion, but by sufficiently prolonging the cone, this reflexion will be diminished, and it will cease when the diameter of the open end includes a large number of wave lengths. Further, he states that, apart from friction, by diminishing the diameter of the narrow end, and at the same time lengthening the cone, it would be possible to obtain from any given source of sound any desired amount of energy, and to transfer this energy from the tube to the surrounding air. This statement suggests the use of conical resonators much larger than those I have yet used. I have observed that the tone is louder when the ear is placed in the axis of the cone than when it receives the sound waves near the side, as if there were a core of greater disturbance passing down the centre of the cone.

II. The Use of Mr Alfred Graham's Apparatus along with Large Resonators.*

6. If we suspend Mr Graham's variable resistance apparatus over the phonograph and connect it with the receiver, in front of which a large resonator is placed, and if an electric circuit is established, the volume of tone is much increased. I usually employ a dry cell battery composed of three Obach's cells. Each cell = 2 volts, and with the resistance of the variable resistance and of the receiver gives a current of about $\frac{1}{3}$ of an ampere. It must be admitted, however, that the quality of tone is altered, sometimes apparently for the better, but at other times for the worse. Thus band records giving complex sounds are often harsh, and the human voice often loses in distinctness of articulation. On the other hand, simpler sounds, such as those of the cornet, bass-tuba, saxophone, and bassoon, are sometimes richer and fuller and more like the tone of the real instrument than when the sounds are strengthened by resonance alone. I have observed that by the electrical method a gain beyond a certain limit of loudness is at the expense of clearness and quality. If one is satisfied with the loudness obtained by using one cell instead of three or four, good quality and distinctness are obtained. This is a point of considerable interest, as it shows that the most complex sound waves can be transmuted by the variable resistance apparatus into electrical waves which, in turn, in the receiving apparatus, cause the ferrotype plate of the latter so to vibrate as to give out tones closely resembling those that originally fell on the glass disk of the phonograph.

III. The Use of a Parabolic Reflector.

7. Reflexion of waves of sound from parabolic surfaces is a well-known phenomenon. Rays of sound diverging from the focus and falling on a paraboloid formed by the revolution of a parabola about its axis will be reflected in directions parallel to the axis. I had a paraboloid constructed of zinc, 40 inches in diameter at the open end, and having its focus 5 inches from the vertex. When the wide end of the brass resonator No. 4 in table is placed in the focus, and the narrow end is connected with the tube leading to the phonograph disk, the sound is reflected with a pleasing effect, owing to the friction noises of the phonograph becoming much less audible than when they escape from the wide end of the resonators Nos. 1 and 2.

IV. The taking of Records.

8. Considerable experience has convinced me that the phonograph will record and faithfully reproduce all manner of sounds, provided these are of sufficient intensity to cause the glass disk to vibrate. When I have failed in obtaining a record, investigation

* I have described this apparatus in *Proceedings Royal Society, Edinburgh*, 1896, p. 47.

has always shown that the fault does not rest so much with the instrument as with the operator. As examples of complex sounds, I have obtained the sound of about 2000 persons singing in a large hall with organ accompaniment, the dashing of the waves on a shingle beach, the hissing produced by the escape of air from an iron cylinder under a pressure of over 200 atmospheres, the sound of a riveter's workshop, and the sound of a military band of about seventy performers. The tones of single instruments are, as a rule, easily taken, and their range as regards pitch is faithfully recorded. Thus, I have records of scales from the deepest tone of the bass-tuba, 28 vibrations per second (the lowest sound in the orchestra except the still lower note of the contra-bassoon, 27 vibrations per second), up to the highest note of the piccolo, 4096 vibrations per second. My collection now includes, taking the instruments in the order of their highest notes, the organ, piccolo, clarinette, harp, flute, piano, violin, guitar, viol d'amour, oboe, saxophone, mandolin, bugle, three-keyed horn, trumpet, cornet, viola, cor anglais, violoncello, alto trombone, tenor trombone, bassoon, bass-tuba, bass trombone. The instruments most difficult to record are those having a wide keyboard, such as the organ, harmonium, and piano. When the sounds proceeding from a series of wires or reeds or pipes stretching over a distance considerably greater than the transverse diameter of the receiving resonator fall on the glass disk of the phonograph, the sounds are not recorded with equal intensity, those coming from the vibrating body immediately in front of the resonator being usually more intense than those coming from vibrating bodies placed more to the sides. This is especially the case when the wide end of the resonator is brought close to the piano, as I have proved by placing the phonograph below the piano and then taking the vibrations from the sounding board immediately overhead. As a rule, both with the organ and piano, the deep pedal notes are not recorded distinctly, and produce jarring sounds probably by the vibrations acting on the loose link between the recording lever and the glass disk. To secure the natural tones of the piano and organ, the phonograph should be placed at a considerable distance from the instrument. The best records I have got from the organ were obtained when the recording phonograph was about forty feet distant from the instrument. Then the balance of the intensity of the various tones is excellent, and although there is a loss in intensity there is a gain in quality and distinctness.

V. The Mechanism of the Recording Point in the English Model.

9. It was a considerable time before I thoroughly understood the way in which the marker made its impression with each vibration on the wax cylinder. The original tinfoil phonograph was so constructed that when the diaphragm was pressed inwards by the condensation of the air wave, the marker made a corresponding depression on the tinfoil, and when the diminution of pressure came on, corresponding to the rarefaction of the air wave, the marker passed away from the tinfoil. There were thus a series of marks the depth of each of which corresponded to the degree of pressure on the dia-

phragm. A hasty inspection of the more complicated apparatus in the English model might lead one to suppose that the action in it was of the same nature, but a more careful scrutiny will show that this is not the case. By the model now exhibited you will see that, when pressure is made on the diaphragm, the effect is to cause the cutting edge of the recording gouge to be directed downwards. As the cutting edge of the gouge is directed against the wax cylinder and is opposed to the rotation of the latter, it is evident that this change of the angle of the gouge to a downward direction will cause the gouge to cut a deeper groove into the wax cylinder. The depth of the groove, as determined by the angular movement, is therefore a measure of the pressure on the glass disk. It must be borne in mind that when no pressure is exerted on the glass disk the marker cuts a groove. When there is greater pressure, by the cutting edge being placed at a larger angle with the tangent of the curved surface of the cylinder, a deeper groove will be cut. On the other hand, when the cutting edge is placed at a smaller angle with the tangent of the curved surface of the cylinder a shallower groove will be ploughed on the surface of the wax cylinder. It follows that, if the sound falling on the wax cylinder of the phonograph be very intense, during the increase of pressure the groove will be deep, and during the diminution of pressure the groove will be shallow; and so great may be the difference between the plus pressure of condensation and the minus pressure of rarefaction that during the latter the recording point will only skim the surface of the wax cylinder, without making any groove. This explains an anomaly in several of the photographs taken of portions of the surface of the wax cylinder. For example, a photograph of a portion of a record taken of sound emitted by a full organ shows deep furrows, continued for a considerable distance, corresponding to the long chord-like sounds of the instrument, and these are succeeded by portions in which there is no groove. This is well seen in the fig. 1 (Plate I.). In this case, so great has been the rebound from the state of great pressure that the cutting edge has only slid along the surface of the wax cylinder without cutting a groove. The same is seen when chords are made by bowing several strings of the violin, as in fig. 2 (Plate I.).

10. It is possible that here we have the explanation of one of the imperfections of the phonograph, or, perhaps, rather an illustration of the wrong way of using the instrument. All who have tried the instrument must have observed that the best effects are obtained by tones of moderate intensity. If too weak, the tones given out on reproduction are only imperfectly heard on account of their weak intensity, and by no system of reinforcement or electrical relays can these be made fairly audible. On the other hand, if too strong, there are two risks:—(1st) The intensity of the tone may cause a jarring between the end of the wire in the loop connecting the wire of the lever with the wire from the glass disk, and, as this is communicated to the glass disk, a noise is produced; and (2nd) the intensity of the tone may be so great as to cause, during the rarefaction of the air corresponding to the diminution of pressure, the recording marker to come to the surface of the wax cylinder, or even to leave it altogether. Suppose the marker just skims the surface, it will produce a friction sound which must affect quality, and suppose the

marker leaves the surface altogether for a fraction of a second, there will be a rebound from the glass disk (owing to the removal of pressure coming from the marker) which is not exactly the same as the diminution of pressure due to the rarefaction of the aerial wave in the immediately preceding vibration. These changes must affect quality of tone.

VI. The Nature of the Marks on the Cylinder

11. Many attempts have been made to obtain tracings of the vibrations of membranes and of glass or metallic disks. In 1856 Leon Scott * invented the well-known phonautograph, which may be regarded as the precursor of the phonograph, and by which vibrations were recorded. Donders,† in 1870, applied the instrument to the investigation of vowel sounds. Next came the logograph of Barlow,‡ by which curves were obtained by the vibrations of a thin membrane of gold-beater's skin. These curves represented the varying pressures of the expelled air taken as a whole, but did not indicate pitch. About 1873 Koenig introduced the method of manometric flames, and flame pictures of vibrations were thus obtained. In 1876 Clarence J. Blake § employed the human membrana tympani as a logograph. In the same year Stein || carried out a method by which he photographed the vibrations of tuning-forks, strings, &c., by attaching to them plates of blackened mica perforated with small holes. A beam of light passing through a hole was allowed to play on a sensitive photographic plate moving with uniform velocity. There was thus recorded a curve representing the combined motions. All of these instruments made it possible to record vibrations, but the sound could not be reproduced from the tracings thus obtained. This was accomplished in 1877 by Edison, by the invention of the phonograph. In 1878 Fleeming Jenkin and Ewing ¶ succeeded in obtaining tracings of the record of vowel sounds on the tinfoil phonograph, and the curves were submitted to harmonic analysis. Shortly afterwards, and in the same year, E. W. Blake ** succeeded in photographing the minute vibrations of a circular ferrotype plate screwed to a telephone mouthpiece by attaching a small mirror to the back of the plate and directing a reflected beam of sunlight on a moving photographic plate. Since that time, the marks on the tinfoil of the first phonograph have been scrutinised by Grützner, Mayer, Graham Bell, Preece, and Lahr.†† The imperfections

* E. L. Scott, *Comptes rendus*, t. 53, p. 108.

† Donders, *De Physiologie der Spraachklanken in het bijzonder van die der nederlandische taal.* Utrecht, 1870.

‡ Barlow, *Trans. of Royal Society*, 1874.

§ Blake, C. J., *Archiv. of Ophthalmology and Otology*, vol. v. 1, 1876.

|| Stein, S. Th., "Die Photographie der Tone," *Poggendorff's Annalen*, 1876, p. 142.

¶ Fleeming Jenkin and Ewing, "On the Harmonic Analysis of certain Vowel Sounds," *Trans. Roy. Soc. Edin.*, vol. xxviii. p. 145.

** Blake, E. W., "A Method of recording Articulate Vibrations by means of Photography," *Amer. Jl. of Science and Arts*, 3rd ser., vol. xvi. p. 54.

†† Referred to in *The Telephone, the Microphone, and the Phonograph*, by Count du Monce, London, 1884. See also *The Speaking Telephone and Talking Phonograph*, by G. B. Prescott, New York, 1878.

of the tinfoil phonograph made progress impossible for ten years (from 1878 to 1888), during which time, however, EDISON, GRAHAM BELL and others were engaged in working out the mechanical details of the wax-cylinder phonograph. The subject was then taken up by HERMANN * of Königsberg, and he succeeded in obtaining photographs of the vibrations produced by the vowel sounds, a beam of light reflected from a small mirror attached to the vibrating disk of the phonograph being allowed to fall on a sensitive plate while the phonograph was slowly travelling. The curves thus obtained were very beautiful, and present a striking resemblance to some of KOENIG's flame pictures. In 1891 BOEKE † of Alkmar, in a laborious microscopical research, measured the transverse diameters of the depressions on the wax cylinder at different depths, and from these measurements calculated the depths of the curves. He thus reconstructed the curves on a large scale. The last attempt at recording sound vibrations by photography that has come under my notice is by WILLIAM HALLOCK ‡ of Columbia College, who has succeeded in photographing the flames of an apparatus somewhat similar to the analyser constructed by KOENIG. Manometric capsules were attached to eight resonators corresponding to the eight tones of a harmonic series, and when the flames were lit, by a device of swinging the camera in front of them, a photograph was obtained of the eight bands of flame, as modified by singing the vowels in front of the resonators.

12. I have endeavoured to study the marks on the wax cylinder in three different ways:—(*a*) Taking a cast of the surface of the cylinder; (*b*) taking a microphotograph of a portion of the surface of the cylinder; and (*c*) recording the curves on a slowly moving surface, by a method to be afterwards described.

A. Casts.

13. As regards the first method, taking casts, which was also attempted by HERMANN and BOEKE,§ the results were not satisfactory. The most efficient method followed by me was to paint on the cylinder, with a camel-hair brush, a layer of celloidin dissolved in ether. This soon hardened and the film could then be peeled off. The thin film thus obtained was then inverted on the stage of a microscope, and the marks were seen in relief, as in fig. 3 (Plate I.). This method had the disadvantage of flattening the curves. The depressions are well seen and their differences as regards length are obvious.

* HERMANN, "Ueber das Verhalten der Vocale am neuen Edisonschen Phonographen," *Pflüger's Archiv*, vol. 47, 1890, p. 42; also *Phonophotographische Untersuchungen*, ii. p. 44; also *Phonophotographische Untersuchungen*, iii. p. 347. See also curves of the phonautograph obtained by PIPPING, *Zeitschrift für Biologie*, vol. xxvii. p. 1, 1890.

† BOEKE, "Mikroskopische Phonogrammstudien," *Pflüger's Archiv*, vol. 50, 1891, p. 297.

‡ HALLOCK, "Photographic record of Sound Analysis," *The American Annual of Photography for* 1896, p. 21.

§ Herr BOEKE informs me in a letter that he obtained casts of the surface of the wax cylinder by covering the surface with very thin tinfoil such as is used for covering chocolate.

B. Photographs.

14. I took numerous photographs, with aid of the microscope and camera, of portions of the surface of the cylinder on which were records of many instruments and of the voice. Specimens of such photographs are shown in figs. 4, 5, 6 (Plate I.). Each figure, from above downwards, represents the $\frac{1}{5}$th of an inch on the surface of the wax magnified fourteen diameters. The grooves seen in each figure are, on the wax cylinder, $\frac{1}{200}$th of an inch apart, and the length of the groove, from above downwards, represents in time the $\frac{1}{64}$th second; that is to say, when each tracing was recorded, the sapphire point of the recorder travelled over the distance represented in magnified proportions in $\frac{1}{64}$th part of a second. By counting the number of indentations or marks, which in a photograph have a curious appearance of being in relief, one can at once determine approximately the pitch of the tone, the vibrations of which make the impression. The tones highest in pitch were obtained from the piccolo and the xylophone, as in figs. 7 and 8 (Plate I.). Here the pitch was about 1920 vibrations per second. In fig. 9 we have a picture of the vibrations produced by the tones of the violin, and it will be seen that they vary in character. Sometimes the marks are a little apart and at other times they blend into each other, the mark widening out as the recording point cut into the wax and then contracting as it receded. It is to be borne in mind that even when the glass disk is not vibrating, the recorder ploughs a groove in the cylinder, and when the glass disk vibrates, each vibration cuts deeper into the groove. The figure of the vibrations of the tones of a flute (fig. 1) shows moniliform markings, indicating that the disk may not, in some instances, return to its position of rest for a short time. In accordance with the description already given of the mechanism of the recording point, it will be seen that, in the figure of the vibrations of the tones of an organ, the intensity of the tone is so great as to cause after each deeply ploughed groove a rebound lifting the recorder on to the surface of the cylinder, or even off the surface altogether. This is the explanation of the smooth spaces between the ends of individual furrows. This action is also well seen in fig. 10, showing the strong vibrations of a tuning-fork. Here one can distinctly observe the slight groove, made by the very tip of the recorder, between the individual vibrations.

15. The accuracy of the phonograph is well illustrated by the four records, figs. 11, 12, 13, and 14. Here we have four records from four of KOENIG'S tuning-forks, the vibration numbers of which are 64, 128, 256, and 512. When the records were taken the cylinder of the phonograph was making as nearly as possible two revolutions per second. Photographs were then obtained of portions of the cylinder representing vertically $\frac{1}{64}$th second. It will be noticed that in fig. 11 there is one mark or vibration in the $\frac{1}{64}$th second; in fig. 12 there are two marks $(64 \times 2 = 128)$; in fig. 13 there are four marks $(64 \times 4 = 256)$; and in fig. 14 there are eight marks $(64 \times 8 = 512)$. As the phonograph travels with remarkable uniformity of speed when it is in good working order, we may rely upon it as an instrument for determining pitch, provided the time

value of a given length of surface is accurately fixed. The photographic method, however, interesting as it may be, is not of great value, as it does not give the forms of the curves represented by the bottoms of the depressions made by each vibration of the disk of the phonograph.

C. Mechanical Tracing of the Curves.

16. A mechanical representation of the curves presents many difficulties. These were so far overcome by the device of JENKIN and EWING with the tinfoil phonograph. The method followed by these observers, which was entirely mechanical, was to cause the disk of the phonograph to record its movements on a drum moved at the same rate as that of the cylinder. As already mentioned, HERMANN photographed the oscillations of a beam of light reflected from a small mirror connected with the disk of the phonograph, the whole apparatus moving slowly. My method consisted in the adaptation of a light lever to a marker connected with the phonograph itself, and so arranged that it (the point of the marker) would travel over all the ups and downs of the phonographic curve on the wax cylinder at an extremely slow rate. The obvious objections to any method of directly recording the ups and downs of the lever is that the inertia of the lever might cause extraneous vibrations, while at the same time the smaller marks on the wax cylinder might be missed. These objections, however, may be removed by (*a*) reducing friction to a minimum, and (*b*) moving the phonograph cylinder so slowly as to make the movement almost invisible to the naked eye. In this way inertia ceases to be a trouble.

17. After various attempts with simple appliances, the apparatus shown in Plate I. was fitted up, and by means of it the taking of curves became comparatively easy.* In fig. 16, Plate I., a diagram of the arrangement is shown as simply as possible. The first apparatus used was not specially made for the experiment, but consisted of fittings in my own laboratory. The motive power for driving the apparatus is a small water motor acting on a wooden wheel. From this wheel two trains of wheels or pulleys pass, the one set, namely, 2, 3, 4, and 5′, being gradually geared down so as to drive the cylinder of the phonograph, 6,† at an extremely slow rate, and the other set, namely, 2′, 3′, and 4′, to drive at a slow rate the recording drum *a*. By this arrangement the rate of rotation of the cylinder of the phonograph is about once in five or six *minutes*, instead of being once in one-half second, the usual speed in recording. The drum, *a*, also moves very slowly, but a little faster (not twice as fast) than the cylinder of the phonograph, the object being to open out the curves somewhat in a linear direction. By attaching an electric arrangement to the axle of the mandril carrying the phonograph cylinder, 6, the time of each revolution of the phonograph cylinder was registered on

* This apparatus has already been described in a short paper written for the *Journal of Anatomy and Physiology*, vol. xxix.

† The cord passes over (*b*), the wheel seen on the left end of the phonograph spindle in the figure showing the instrument. The wheel will be recognised by a tape band passing vertically over it.

the drum a. Thus the amount of surface on a, representing one-half second on cylinder 6, could always be measured. As a rule, it was found that 3 inches of the drum a represented one-tenth of a second. Occasionally it was one-seventh of a second, but it could be so timed as to represent one-tenth.

18. In the next place, a light lever of hard wood, braced like the mast of a ship, was fixed firmly into a socket bored into the lead weight, $i\ k$, seen in fig. 16, Plate I. This square leaden weight is hinged to the frame carrying the recording and reproducing part of the phonograph by the hinge h, a slot is cut in the under surface of the lead weight, as seen in fig. 17, Plate I., and the marker, $a\ n$ (also $m\ n$ in fig. 16), moves on an axle delicately pivoted to the sides of the slot. In fig. 16, at the end of m, is seen the wire, w, passing up to the glass disk, d, of the phonograph. It will be seen that the point of $m\ n$ touches the surface of the wax cylinder, o, o, o, o. The lead weight accurately follows the movements of $m\ n$, the marker, and the lever s records these movements, as seen in fig. 15, on the drum a. The slowness of movement does away with any movement of s, except that which is communicated to it from the lead weight and from the marker, $m\ n$, and to prevent all extraneous vibrations the phonograph was seated on a solid stone pillar erected for a galvanometer. The point of the lever s is the point of a very fine hard needle, and a was covered with very smooth paper, carefully smoked. As the marker of the phonograph is always travelling to the one side so as to describe a spiral groove, that is, towards the observer, when one looks at fig. 15, it is evident that the point of the lever x would soon leave the surface of a. To get rid of this difficulty, the drum a is mounted on a kind of movable table moving in slots, and controlled by the fine screw c (one thousand to the inch thread). And thus it was easy, by a turn of c, to keep the point of x in contact with the surface of a. Finally, the movable table rested on a plate of metal moving vertically in slots by turning the fine screw b, and thus, after a tracing had been taken once round a, it was easy to move a a little up or down without disturbing the lever x (fig. 15). Thus I had three motions of a, vertical, rotatory, and horizontal, and there were two movements of the cylinder of the phonograph b, rotatory and horizontal. Everything was as steady as it could be made, and the apparatus worked almost automatically, the point n (fig. 16) slowly *crawling* over the surface of the wax cylinder o, about 600 times slower than when the record was made on the wax cylinder.

19. After tracings had been taken, the paper on a was varnished and it was cut into longitudinal strips, each 3 inches in length, and the strips were mounted between two ordinary microscope slides (English make) in the way that slides are prepared for the lantern. Such slips can then be examined by the microscope and the curves may be drawn by ABBE'S camera lucida, or any portion of the tracing may be photographed by a convenient microphotographic apparatus. Thus the size of the curves may be much increased, and so made available for purposes of harmonic analysis.

20. This apparatus, which was large and clumsy, was discarded for the small and more convenient apparatus, consisting of a train of four sets of wheels and

pinions, so geared as to obtain a gradually diminishing rate of motion. Pinions on the axles of the wheels serve for cords by which the phonograph and also the recording drum may be driven at various rates of speed. This apparatus may be so worked as to cause the cylinder of the phonograph to perform one revolution in one hour instead of in half a second. The lever gave an amplification of seventy times, and as many of the marks obtained on the recording cylinder were only about $\frac{1}{30}$th inch in vertical height, it follows that the depths of many of the depressions on the wax cylinder were not more than $\frac{1}{2000}$th of an inch.

21. It has already been pointed out that with the view of opening out the curves the recording drum was caused to move faster than the phonograph cylinder. Unless this had been done, the curves of the individual vibrations would have crowded so close together as to make it impossible to view them distinctly. This will be evident if we look at one of the photographs (fig. 4, Plate I.), representing in vertical length the one-fifth of an inch. In this distance we may have from ten to twenty depressions, and if these had been recorded on the same longitudinal extent of surface on the recording cylinder, we would have had ten to twenty little waves in the one-fifth of an inch. But, if an analysis of the curves has to be undertaken, it is not necessary to have the cylinder of the phonograph and the recording cylinder travelling at the same rate. Even although the latter moves faster than the former, this is of no consequence as the coefficients of the harmonic series are altered all in the same ratio. It does not matter what may be the *form* of the curve representing an individual vibration. This might be either an exact facsimile of the depression on the wax or it may be drawn out by causing the recording drum to move faster. Whatever be its form, if the curve is built up of a series of curves that are members of a harmonic series, these constituents can always be determined.

22. Specimens of the curves thus obtained are shown in figs. 8 to 18, Plate II. It will be seen that they vary much in character.

VII. A Method of Recording Variations of Intensity of the Sounds of the Phonograph.

23. Suppose a series of sound waves of gradually increasing intensity to fall on the disk of the phonograph, the pressure on the disk will gradually increase and the normal groove will be cut deeper. In this process each vibration will be a little deeper than the one immediately before it, but the difference in depth will be very small. If the increase of pressure of the note or chord lasted more than half a second, the extent of surface covered by the recording point during that time would be nearly 7 inches, and there might be from 500 to 1000 depressions in that distance. Suppose, now, that we recorded all these little depressions by the slow moving lever method, it will be evident that the gradually increasing differences in height of the little curves would scarcely be appreciable.

The slow method of recording vibrations, therefore, whilst it is the method by which data can be obtained that have to do with pitch and quality, will fail in giving us a record of variations in intensity. This aspect of the matter came under my notice at an early period of the investigation. So far as I am aware, no one has attacked this side of the problem. Nothing is more striking in listening to the phonograph when it is reproducing either human speech or musical sounds than the way in which it catches every inflection of the voice or the slightest emphasis, diminuendo, and crescendo of the sound. This must be due to variations of pressure. How may these variations be recorded?

24. The most evident method is to attempt to record mechanically the variations in an electro-magnet produced by pressures on a variable resistance apparatus in the same circuit. My first attempt was to place GRAHAM'S transmitter over the glass disk of the phonograph and to place in the same circuit an electro-magnetic marker such as is used for physiological purposes. This gave poor results, but still they were encouraging. On placing a BREGUET'S chronograph in circuit the results were much better, and it was evident that there was a movement of the vibrator of the chronograph for each note or chord emitted by the phonograph. I then heard of an ingenious apparatus devised by HEURTLEY of Breslau, by which he has succeeded in recording by electrical and mechanical arrangements the sounds of the heart. His apparatus consists essentially of a large stethoscope on which a peculiar resonator is fixed. The resonator carries a small wooden tuning-fork, between the prongs of which is fixed a simple microphonic contact of two carbon buttons. This is one half of the apparatus. The other half consists of an electro-magnet, over the poles of which is fixed, face downwards, a shallow tambour, of the Marey pattern, having on its under surface a broad ferrotype plate. This tambour is then connected with an extremely delicate recording tambour. When I heard of this apparatus I at once saw that the second half of it was exactly what I wanted for the phonograph work, and, by the kindness of Professor HEURTLEY, the apparatus was made for me in Tubingen without delay. When placed in the circuit along with the carbon transmitter the pen of the recording tambour moves at right angles to the line of revolution of the cylinder with each tone and chord played by the phonograph. When the ear perceives tones of considerable intensity the lever point is seen moving through a greater distance than when the tones are weaker; consequently we have a graphic record of the variations in intensity. If the recording cylinder is timed to travel at the same rate as the cylinder of the phonograph, then the curves on the former exactly correspond to the ensemble of the minute marks on the latter corresponding to a particular variation in intensity. When the recording cylinder is caused to travel as fast as the phonograph cylinder, the variation in the heights of the curves recorded on the revolving cylinder is not so apparent as when the recording cylinder travels more slowly. It is easy, however, to time the rate of revolution of both cylinders by a chronograph. Thus I have found that when the recording cylinder is travelling at such a rate that $\frac{1}{4}$ inch of surface corresponds to one-fourth of a second, an

easily read tracing is obtained. In such a distance we may have one little wave representing the pressure of a chord lasting for one-fourth of a second, or we may have from two to as many as fifteen little waves, often varying much in general character. Suppose we find as many as fifteen; then each must have lasted not more than $\frac{1}{60}$th of a second. Even then the ear is able to follow the individual notes, when the phonograph is listened to simultaneously. This may be readily done either by listening directly to the phonograph or by connecting a telephone with the secondary of an induction coil, while the current in which the variable resistance apparatus is interposed passed through the primary. If, then, we hold the telephone to the ear while we look at the little pen writing on the recording drum, it is easy to see that the sensations are simultaneous. Now if a note of a pitch say of 300 vibrations per second lasts only $\frac{1}{60}$th of a second, it is evident that only five vibrations must have occurred in that time. This shows that we can appreciate a tone and decide as to its pitch if only five vibrations fall on the ear. This conclusion coincides with the opinion I arrived at during last summer from a careful inspection of the photographs and of the mechanically recorded curves. Of course I assume that the music is being played by the phonograph in its proper *tempo*. If the phonograph is made to travel faster, possibly it might be found that pitch might be appreciated for even shorter periods. Examination of the curves shows that as a rule no "chord" lasts longer than half a second. This method of recording seems well suited to the study of the time relations if a series of complex sounds pour in upon the ear.

25. If one doubts whether the movements of the recording lever coincide with the tones of the phonograph, three ways are open by which the statement may be put to the test:—(1) Listen attentively with the telephone and at the same time watch the recording point. The sensations of hearing and of vision for any particular note are simultaneous. (2) Remove the elastic tube from the recording tambour and place it in the ear and the music will be heard. (3) Lead the elastic tube from the electric tambour to a recording phonograph, and a feeble record will be obtained of the music showing that all the vibrations are present. In the two last experiments, as might be expected, quality suffers, but the rhythm, the *tempo*, and the general character of the tune are reproduced. Examples of such tracings are shown in fig. 5 (Plate II.).

VIII. The Effect of Reversing the Action of the Phonograph.

26. Long ago, with the tinfoil phonograph it was noticed that, with speech, if the movement of the cylinder was reversed, there was a reversal of the sounds. I recollect that in 1878 Lord Kelvin and I often repeated this experiment. Recently I have re-examined this matter with the aid of a phonograph in which a reversed movement has been obtained by a change in the position of the brushes of the electric motor that drives the machine. It will be observed that this is the most evident way of obtaining a reversed action. It will not be obtained by simply reversing the wax cylinder on the india-rubber mandril of the machine, because, in the first place, the wax cylinder is of

unequal thickness at each end to suit the tapering form of the mandril and it cannot be put on in a reverse position, and, in the second, when the wax cylinder is in its normal position a spiral groove is cut from left to right, and if it were reversed it would pass from right to left, while the feeding screw of the machine which secures the motion from left to right would still be moving in that direction. Having secured the reversal, it is easy to show that words pronounced backwards to a phonograph moving in the direction of left to right and then reproduced from a phonograph moving in the direction of right to left are uttered normally and with considerable distinctness.

Thus the sounds—

Fargonof	become	Fonograf
Nōfelet	,,	Telephōn
Fārgelet	,,	Telegrāf
Pokselet	,,	Teleskop
Arrubnidē	,,	Edinburrā
Wogsalg	,,	Glasgow
Elponitnatsnoc	,,	Constantinople
Eetisrevinū	,,	Universitēe.

The difficulty, of course, is in emphasising the proper syllables. In pronouncing a word backwards not only may the emphasis be placed on the wrong syllable but suppose that in an emphasis one begins the sound crescendo and ends it off diminuendo, when the reversal takes place we have the opposite, often giving a ludicrous effect. This is well observed on listening to reversed music. Not only are all one's notions of the relations of tones thrown into confusion, but as with many instruments the tone is sharply and distinctly taken and then is allowed to weaken in intensity, the effect is produced of tones beginning diminuendo and ending loudly and abruptly. Still it is interesting to find that such tones as those of the vowel sounds, flute tones, cornet tones, and forks, if spoken, sung, or played smoothly, and, as far as possible, with a uniform intensity, come out with equal distinctness and, so far as I can observe, with very little if any alteration in quality, whether they are taken normally or reversed. No experiment could illustrate more strikingly the dependence of quality of tone on the resultant wave forms imprinted on the cylinder of the phonograph. At the same time, I am not convinced that with the means at our disposal we have yet obtained an absolutely accurate reversal. This criticism was first suggested to me by Professor TAIT some time ago, and a careful scrutiny of the marks shows that he is right. The depression made on the wax cylinder for a given vibration does not seem to be deepest in the centre, but the maximum dip is nearer one end while there is a tail or "trail out" as the pressure is removed. The direction of the trail out is opposed to that in which the cylinder is travelling, and as the cylinder travels with great velocity, the trail out is quite appreciable. Were the phonograph a perfect machine, the maximum depth of the curves made by compound tones or by harmonies would be in the centre, and the form of the curve, corresponding to the periodic variations of air pressure, would depend on the sum of its

components varying separately according to the simple harmonic law. If we take as an example a harmony, the variation of the air pressure of a harmony is the sum of the variations of simple tones, one having a period equal to the period of the harmony, a second $\frac{1}{2}$, a third $\frac{1}{3}$, and so on.* It may be that this defect in the form of the curve in the phonograph is the explanation of the fact that it does not, in many cases, reproduce absolutely the quality of tone. Further, when reversal takes place, it will be evident that the reproducing point will run down the slope that corresponds to diminution of pressure before it runs up the slope corresponding to increase of pressure, and that it will take longer time in going down than in going up the slope. This, again, must affect quality.

IX. Remarks on Discrimination of Auditory Sensations.

27. This study of the phonograph has led to the consideration of some of the fundamental questions of physiological acoustics, but I shall briefly refer to only one of these at present. It is clear that by the aid of the phonograph we can record vibrations of higher number than by any other method at our disposal, and that we can see and study the time relations of these vibrations. This is a direction in which research should proceed. So far as I am concerned, I must leave it to others. By this method, for example, direct observations might be made on the limits of the sensible discrimination of tones. It is well known that the lower limit of tone perception is near 16, and the upper limit near 50,000 vibrations per second, and it is also well known that sensible discrimination diminishes towards each end of the range, and more especially towards the upper limits. By noticing the smallest changes in different determinations, and by the method of computing right and wrong cases in observations of the comparison of differences, experimental psychologists have shown that, between 64 and 1024 vibrations per second, the least noticeable difference is so small as 0·2 vibration. It is said to be 0·4 at 32 and 2048 vibrations per second. It is certainly a remarkable testimony to the delicacy of the ear that, between 32 and 2048 vibrations per second, we can observe a difference of less than 1. Even the most skilled ear cannot observe large differences between 12,288 and 16,384, and Külpe states that only about 23 tones can be distinguished beyond 4096. From these data, we can compute, as has been done by Külpe,† the number of tones that the ear can distinguish. Thus, in the range of human audibility, we can hear about 97 tones between 16 and 64 vibrations per second, 4800 between 65 and 1024, 6144 between 1025 and 4096, and 23 on the high side of 4097. This gives a total of 11,064 tones heard by the human ear. It is interesting, in this connection, to notice the range as regards pitch of the chief instru-

* Lord Kelvin, "On Beats of Imperfect Harmonies," *Proc. Royal Society of Edinburgh*, 1st April 1878; also in *Popular Lectures and Addresses*, vol. ii. p. 395.

† Oswald Külpe, *Outlines of Psychology, based upon the results of experimental investigation*, p. 106, trans. by E. B. Titchener, 1895.

ments, as shown in the diagram on Plate III., showing the pitch of the highest and of the lowest tones. The highest tone is that of the piccolo stop of the organ = 4096 vibrations per second, while the lowest is the deepest tone of the contra-bassoon, the vibration number of which is 27.

28. Now the interesting question arises, which was discussed by HELMHOLTZ with the data then at his disposal, of how the ear appreciates this vast number of tones, and how it is that we have the power of analysing compound periodic vibrations into their simplest constituents. Further, it is well known that the tones we thus sift from each other by analysis correspond to the simple vibrations that are shown by mathematical physics to exist in the compound movement. Now we know that such an analysis can be made by a suitably arranged acoustical apparatus, and it seems to follow that probably in the cochlea we might find structures presumably capable of doing such work. Without discussing possible theories of the cochlea, we may assume that it might work in one of two ways. Either small vibratile bodies would be introduced between the pressures sent into the organ and the filaments of the auditory nerve, or that individual nerve fibres were directly excitable by waves of a definite wave length, and that they thus had a selective action. It will be observed, however, that in either supposition the individual nerve fibres would convey impulses corresponding to the number of vibrations of the tone selected, as ably argued by Professor RUTHERFORD,* and it does not follow that the number of nervous impulses sent along the filaments of the auditory nerve would be independent of the number of stimuli given to the specially tuned vibratile bodies that are supposed, *ex hypothesi*, to be at their commencements.† To aid, then, in discussing this question, it is of interest to ascertain whether, as a matter of fact, and without considering their mode of action, there are a sufficient number of bodies in the cochlea presumably capable of acting as intermediate structures. I have collected data on this point both from observations and measurements made in my own laboratory, and from the exhaustive account of the cochlea given by RETZIUS.

1. *Audible sounds* = 11,064
   Less those below 64 and above 4096 = 110
   Leaving . . 10,954
   Say . . 11,000

2. *Distribution of audible sounds in six octaves used in music.*
   $\frac{11,000}{6} = 1833$ each octave; $\frac{1833}{12} = 153$ each semitone.
   Musician's ear can detect difference of pitch in tuning a violin of $\frac{1}{64}$ semitone.
   $\frac{153}{64} = 2{\cdot}4$ for each $\frac{1}{64}$ semitone.

1. *Nerve fibres in human auditory nerve*, 14,000.
   Range of audibility, 11 octaves.
   $\frac{14,000}{11} = 1273$ fibres for each octave.

* RUTHERFORD, *Address to British Association for Advancement of Science*, 1887.

† HELMHOLTZ, *Sensations of Tone*, trans. by A. I. ELLIS, p. 221.

Assuming that the number of auditory filaments is the same for each of the eleven octaves, which is unlikely, the probability being that there will be fewer for the range below 64 and above 4096.

$1273 \times 6 = 7638$ for the six octaves under consideration.

$\frac{1273}{12} = 106$ fibres for each semitone.

$\frac{106}{64} =$ *Less than 2 fibres for each* $\frac{1}{64}$ *of a semitone.*

2. *Fibres in Membrana basilaris*, 24,000.

$\frac{24{,}000}{11} = 2182$ fibres for each octave.

$2182 \times 6 = 13{,}092$ for the six octaves under consideration.

$\frac{2182}{12} = 180$ fibres for each semitone.

$\frac{180}{64} =$ *Less than 3 fibres for each* $\frac{1}{64}$ *of a semitone.*

3. *Hair Cells: Inner*, 3487; *Outer*, $11{,}750 = 15{,}237$.

$\frac{15{,}237}{11} = 1385$ cells for each octave.

$1385 \times 6 = 8310$ hair cells for the six octaves under consideration.

$\frac{1385}{12} = 115$ cells for each semitone.

$\frac{115}{64} =$ *Less than 2 for each* $\frac{1}{64}$ *semitone.*

4. *Corti's Rods: Inner*, 5590; *Outer*, $3848 = 9438$.

$\frac{9438}{11} = 858$ rods for each octave.

$858 \times 6 = 5148$ rods for six octaves under consideration.

$\frac{858}{12} = 71$ for each semitone.

$\frac{71}{61} =$ *at least one rod for each* $\frac{1}{64}$ *semitone.*

As there is a high probability that there are fewer nerve fibres for the five octaves left out of consideration, and consequently more in the six octaves used in music, it follows that we have in the cochlea a sufficient number of possibly vibratile masses to satisfy the demands of theory.

29. The view that the cochlea is a differential apparatus is also supported by the fact that careful measurements made of the same parts of the organ in man, the cat, and rabbit show considerable variations, variations that correspond also with all we know of the auditory powers of these examples. These measurements also help to give one a conception of the relative dimensions of different parts of the organ, and, to make this more obvious, I have given a column in which the measurement has been multiplied by one hundred. These measurements have been collected chiefly from the works of RETZIUS :—

a. *Lengths of Cochlear portion of Internal Ear in Man, Cat, and Rabbit.*

	Membrana basilaris and papilla basilaris.			*Ductus cochlearis.*		
	mm.	inch.	100 times.	mm.	inch.	100 times.
Man, .	35·5	1·42	142	36	1·44	144
Cat, . .	23·5	0·94	94	25	1·00	100
Rabbit, .	15·0	0·60	60	16	·64	64

b. *Radial Breadth of Vestibular Wall.*

	mm.	inch.	1000 times.
Base,	·81	·0324	32·4
Middle,	·88	·0325	32·5
Apex,	·85	·0340	34·0

Vestibular wall increases from base to apex.

c. *Radial Breadth of Tympanic Wall.*

	mm.	inch.	1000 times.
Base,	·45	·018	18
Middle,	·77	·030	30
Apex,	·80	·032	32

Tympanic wall increases from base to apex.

d. *Height of Outer Wall.*

	mm.	inch.	1000 times.
Base,	·585	·023	23
Middle,	·500	·020	20
Apex,	·350 to ·4	·030	30

Outer wall diminishes towards the centre and then increases.

e. *Height of the Tunnel.*

	mm.	inch.	1000 times.
Base,	·028	·00112	1·12
Middle,	·045	·00180	1·18
Apex,	·049	·00196	1·96

Tunnel becomes higher as we pass from base to apex.

f. *Radial Breadth of the Membrana Basilaris (from Habenula Perforata to the Spiral Ligament).*

	mm.	inch.	1000 times.
Base,	·21	·0084	8·4
Middle,	·34	·0120	12·0
Apex,	·36	·0144	14·0

The basilar membrane increases towards the apex.

g. *Radial Breadth of Limbus Spiralis.*

	mm.	inch.	1000 times.
Base,	·243	·0972	97·2
Middle,	·230	·0920	92·0
Apex,	·225	·0900	90·0

The spiral bony shelf diminishes towards the apex as the basilar membrane increases.

Thus, magnified 1000 *times. In inches.*

	Limbus.	Basilar Membrane.	Total.
Base,	97·2	8·4	105·6
Middle,	92·0	12·0	104·0
Apex,	90·0	14·0	104·0

h. *Pillars.*

Length of Inner Pillars.

	mm.	inch.	1000 times.
Base,	·048	·00172	1·72
Middle,	·068	·00272	2·72
Apex,	·070	·00280	2·80

Length of Outer Pillars.

Base,	·062	·00248	2·48
Middle,	·100	·00400	4·00
Apex,	·103	·00412	4·12

As we pass from base to apex both pillars lengthen.

i. *Hair Cells.*

Length of Inner Hair Cells.

	mm.	inch.	1000 times.
Base,	·018	·00072	·72
Middle,	·024	·00096	·96
Apex,	·024	·00096	·96

Length of Outer Hair Cells.

Base,	·03	·0012	1·2
Middle,	·04	·0016	1·6
Apex,	·04	·0016	1·6

*As we pass from base to apex, **both inner** and outer hair cells increase in size.*

k. *Length of the Hairs of the **Hair Cells.***

Hairs of Outer Cells.

	mm.	inch.	1000 times.
Base,	·0045	·00018	·18
Middle,	·0060	·00024	·24
Apex,	·0080	·00022	·22

Hairs of Inner Cells.

Base,	·0045	·00018	·18
Middle,	·0055	·00022	·22
Apex,	·0055	·00022	·22

(1) *In both, **the hairs increase** in length from base to apex.*
(2) *The increase is **greater in** the hairs of the outer cells.*

l. *Radial Breadth of Membrana **Tectoria, covering** Corti's Organ.*

	mm.	inch.	1000 times.
Base,	·285	·0114	11·40
Middle,	·340	·0136	13·60
Apex,	·345	·0138	13·80

*It increases from base to apex, like the **basilar membrane**, but it is not far off one-third of the breadth of this membrane.*

m. *Comparison of Man, Cat, and **Rabbit.***

	Man.	Cat.	Rabbit.
Ear teeth,	2,490	2,430	1,550
Holes in Habenula for nerves,	3,985	2,780	1,650
Inner rods,	5,590	4,700	2,800
Outer rods,	3,848	3,300	1,940
Inner hair cells (one row),	3,487	2,600	1,600
Outer hair cells (several rows),	11,750	9,900	6,100
Fibres in basilar membrane,	23,750	15,700	10,500

DESCRIPTION OF PLATES.

Plate I.

[In Figs. 1–14 (except Figs. 3 and 6), the vertical length of the tracing represents $\frac{1}{64}$th sec., and the cylinder rotates from the bottom to the top of each tracing.]

Fig. 1. Full organ, taken 40 feet from instrument. Portion of Mendelssohn's Wedding March.
Fig. 2. Chords on violin.
Fig. 3. Portion of a celloidin cast of cylinder on which was recorded a march by a military band.
Fig. 4. Flute.
Fig. 5. Tenor voice.
Fig. 6. Violin, quick playing.
Fig. 7. Piccolo.
Fig. 8. Xylophone.
Fig. 9. Tuning fork.
Fig. 10. Tuning fork, 64 vibs. p. sec. (one long mark).
Fig. 11. Tuning fork, 128 vibs. p. sec. (two marks).
Fig. 12. Tuning fork, 256 vibs. p. sec. (four marks).
Fig. 13. Tuning fork, 512 vibs. p. sec. (eight marks).
Fig. 14. Tenor voice (second record).
Fig. 15. Diagram of recording apparatus described in text.
Fig. 16. Shows on a larger scale than in fig. 15 the recording arrangement.
Fig. 17. Under surface of leaden weight to which recording lever was attached.
Fig. 18. Facsimile of curves obtained from record of old English coach horn.
Fig. 19. Facsimile of curves obtained from record of a military band.

Note on Figs. 18 *and* 19.—These curves (3 inches of the tracing representing $\frac{1}{10}$th sec.; that is to say, the curves in 3 inches were recorded on the cylinder of the phonograph in $\frac{1}{10}$th sec.) should be examined with a magnifying glass. In the two upper lines of 18, note the uniform character of the curves. In the third line the character of the curve alters. These are tracings of the marks produced by the long-drawn-out, clear, piercing tones of the horn. In 18, the upper and lower lines show great variety of curve form. The middle line shows no curves, and probably represents an interval of silence.

Plate II.

[*Note.*—Tracings in Figs. 1, 2, 3, and 4 to be read from right to left.]

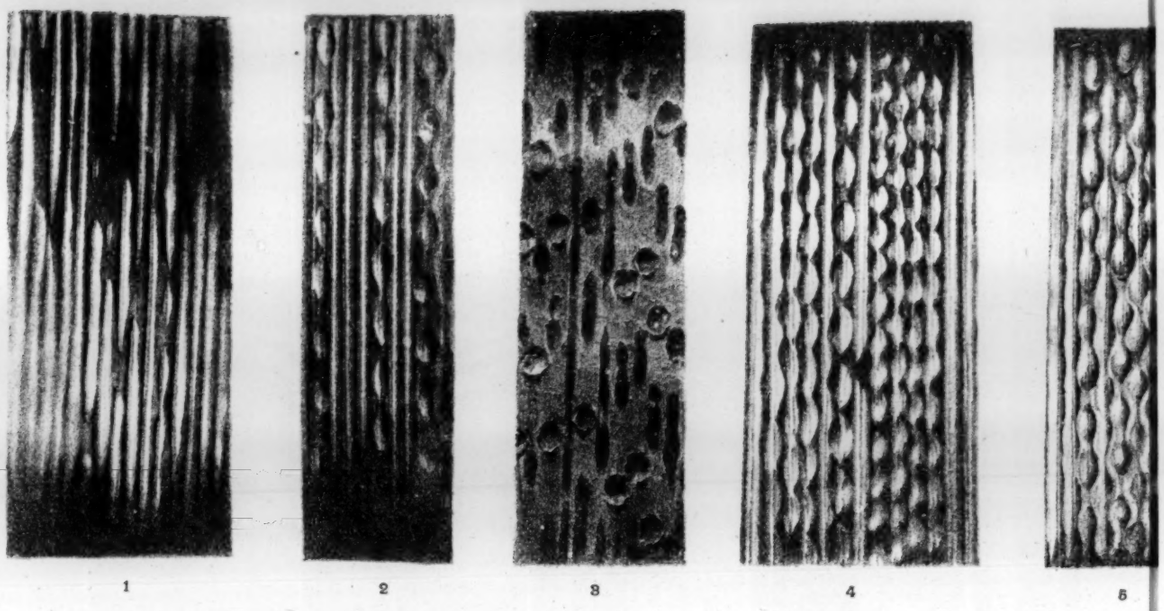
Fig. 1. Facsimile of the vibrations in the words "Tit for Tat."
Fig. 2. Facsimile of the vibrations in the word "University." See description of next fig.
Fig. 3. Facsimile of the vibrations in the words "Glasgow" and "University." The word "Glasgow" is in the upper line, and it will be observed that the marker was raised a little to the left of the beginning. The word "University" is in the lower line, "Univer" to the right, then a short pause, and then the end of the word, "sity."
Fig. 4. Facsimile of the vibrations in the word "Glasgow."
Fig. 5. Tracings taken with the apparatus described in paragraph 24 of the paper. They are to be read from left to right. They represent the variations in intensity of the notes and chords of a military band. Each wave represents a note or chord, and the height of the wave indicates the intensity. A length of one-quarter of an inch represents the impulses communicated from the phonograph to the microphone in one quarter of a second, that is, in the time occupied by half a revolution of the phonograph cylinder when the sound is reproduced. A careful examination will show that portions of the music are repeated. See the uniform waves in lines 3 and 6. These represent blows on an anvil, as produced in the "anvil chorus," of which this is a reproduction.

Note.—Figs. 6–18 are from microphotographs of curves similar (though varying in amplitude) to those in figs. 18 and 19 in Plate I., and in Figs. 1, 2, 3, and 4 of this plate. They are magnified from 5–10 diameters. Only short portions of the curves are given to illustrate the great variety in form.

Fig. 6. Tuning fork, 32 vibs. p. sec.
Fig. 7. Cornet.
Fig. 8. Old English coach horn.
Fig. 9. Bassoon.
Fig. 10. Bassoon.
Fig. 11. Cornet.
Fig. 12. Military band.
Fig. 13. Military band.
Fig. 14. Flute.
Fig. 15. Piccolo.
Fig. 16. Piccolo.
Fig. 17. Piccolo.
Fig. 18. Coach horn.

Note.—The curves shown in Figs. 19, 20, 21, and 22 were taken with a syphon-recorder, to be described in a subsequent communication. It will be seen that they are a great advance on the curves obtained by the older methods. One inch of these tracings represent $\frac{1}{100}$ of a second. By counting the number of waves in this distance, the pitch can be determined.

Fig. 19. Cornet.
Fig. 20. Piccolo.
Fig. 21. Curves of a noise. From the record of the noises in a boiler-maker's shop. Note the irregularities of the curves.
Fig. 22. Song by a tenor voice. Note the gradation from one pitch to another. At the right and left ends of the tracing, the voice was sounding a note a little above the middle C, and in the middle the pitch was about an octave lower.



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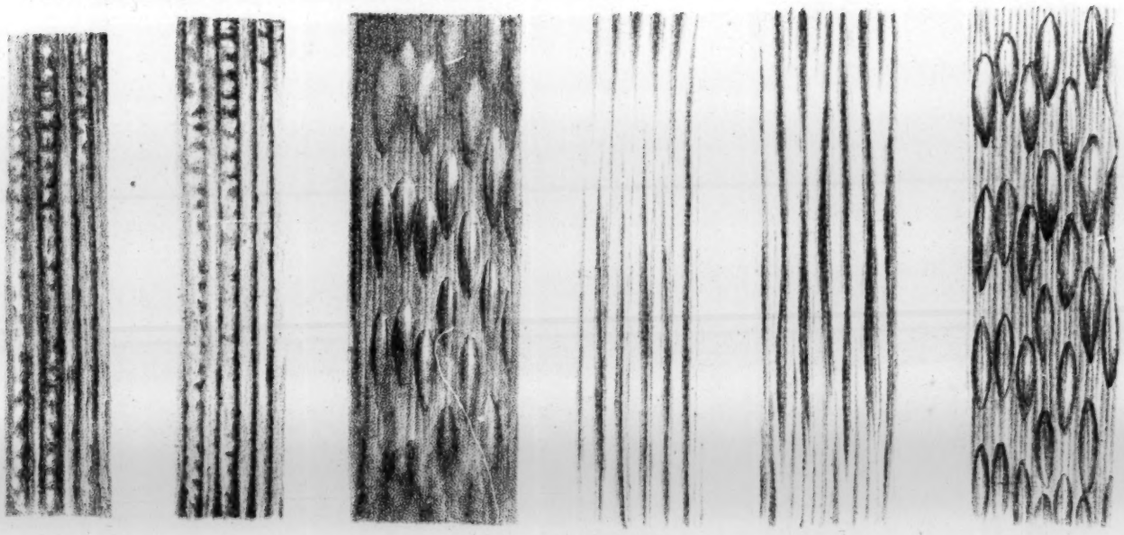

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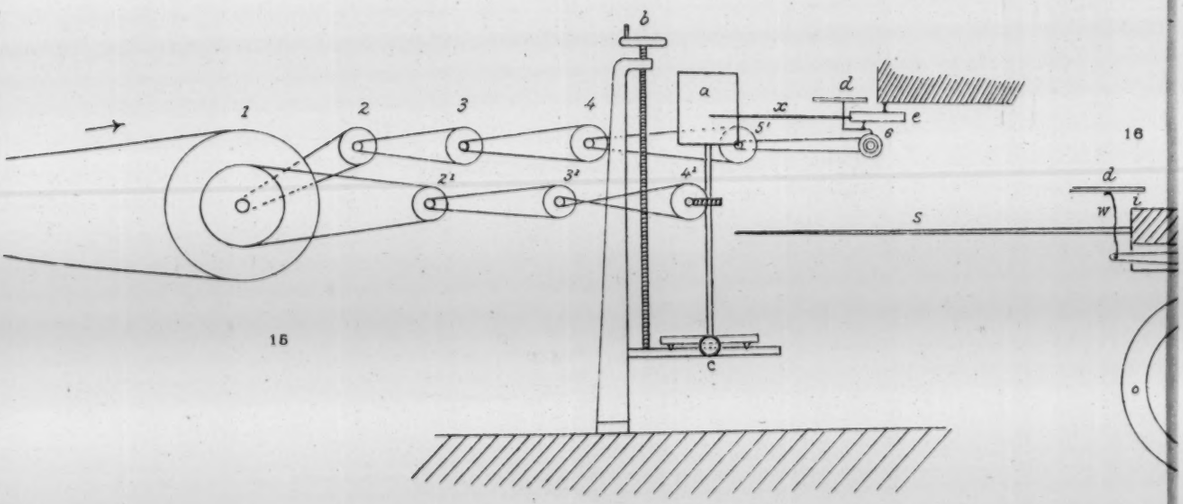

15 16

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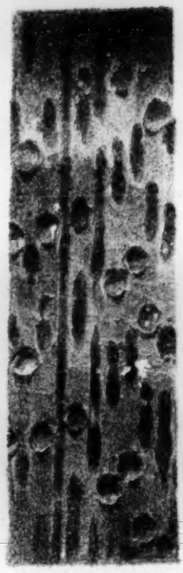

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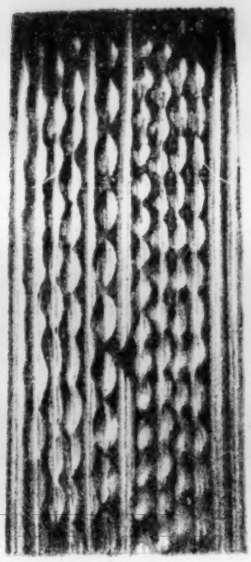

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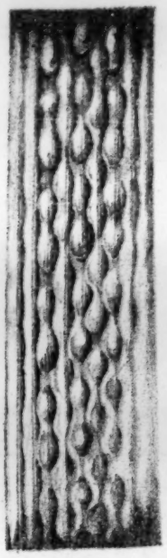

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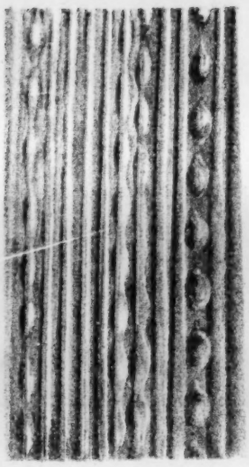

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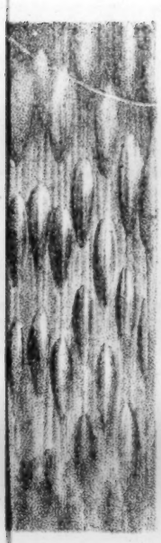

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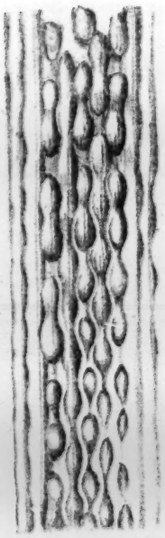

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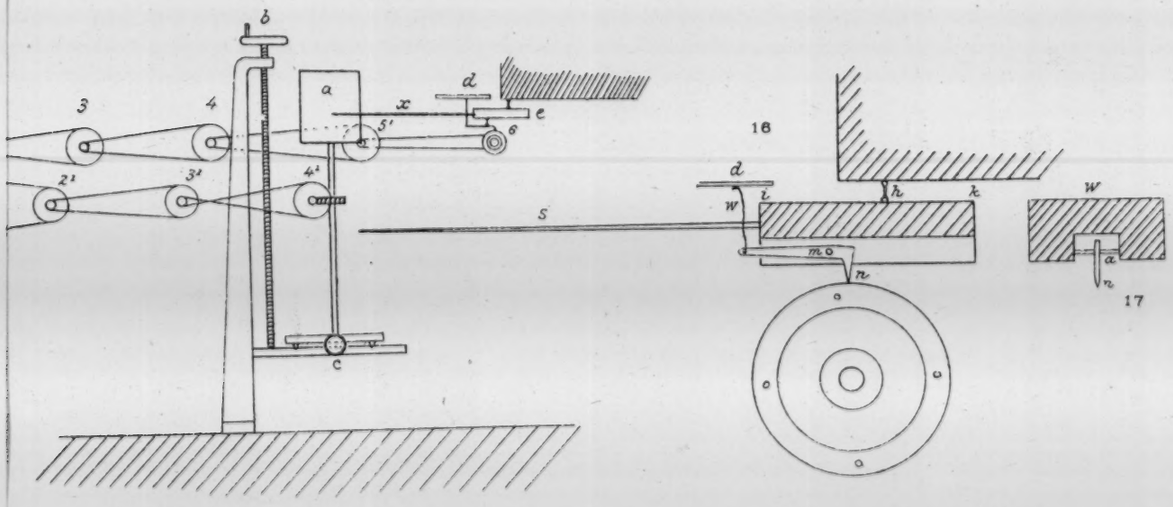

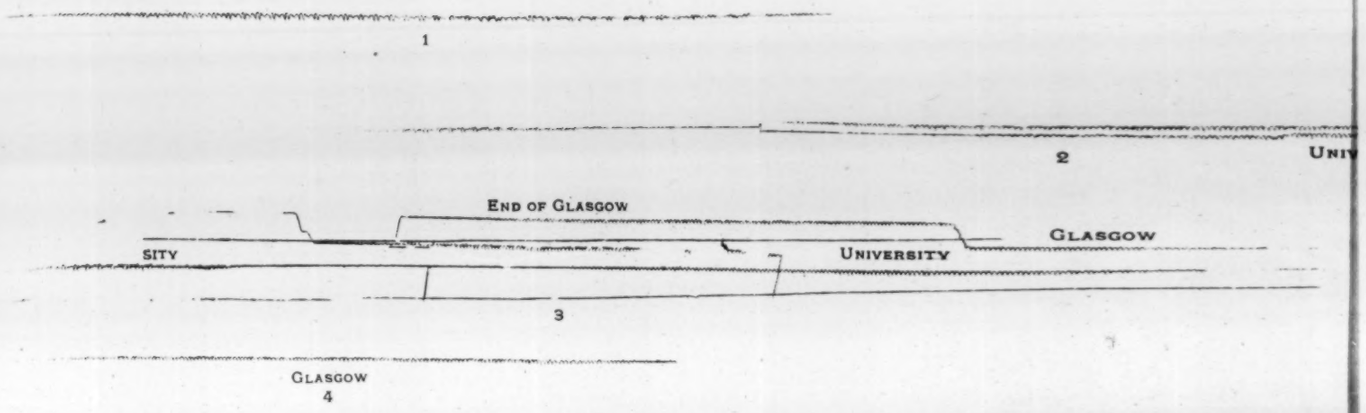
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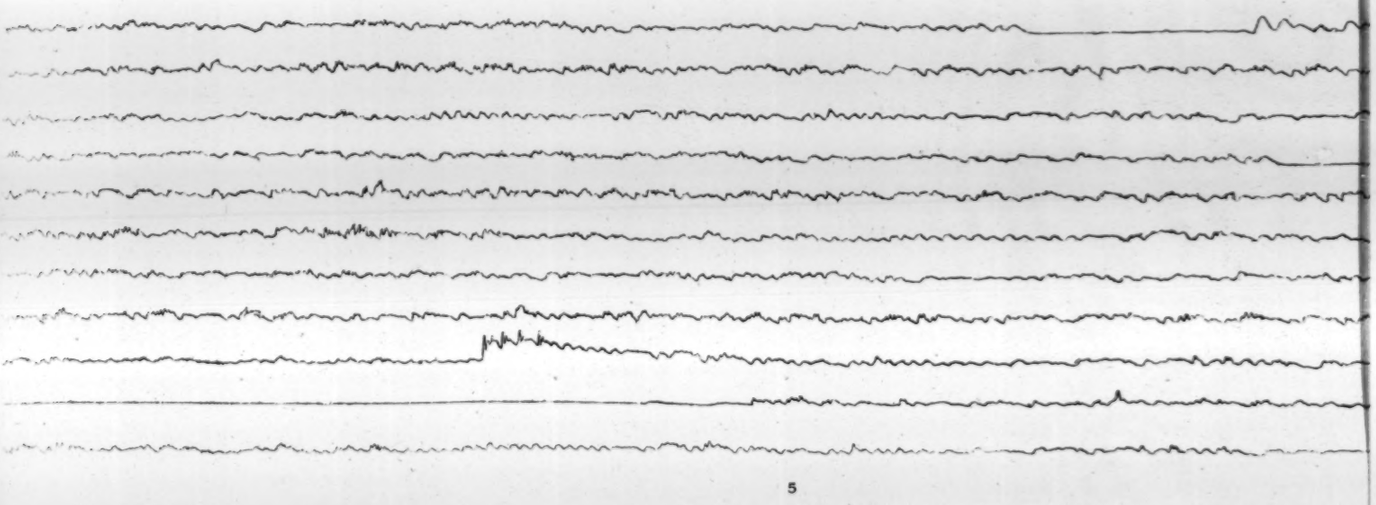
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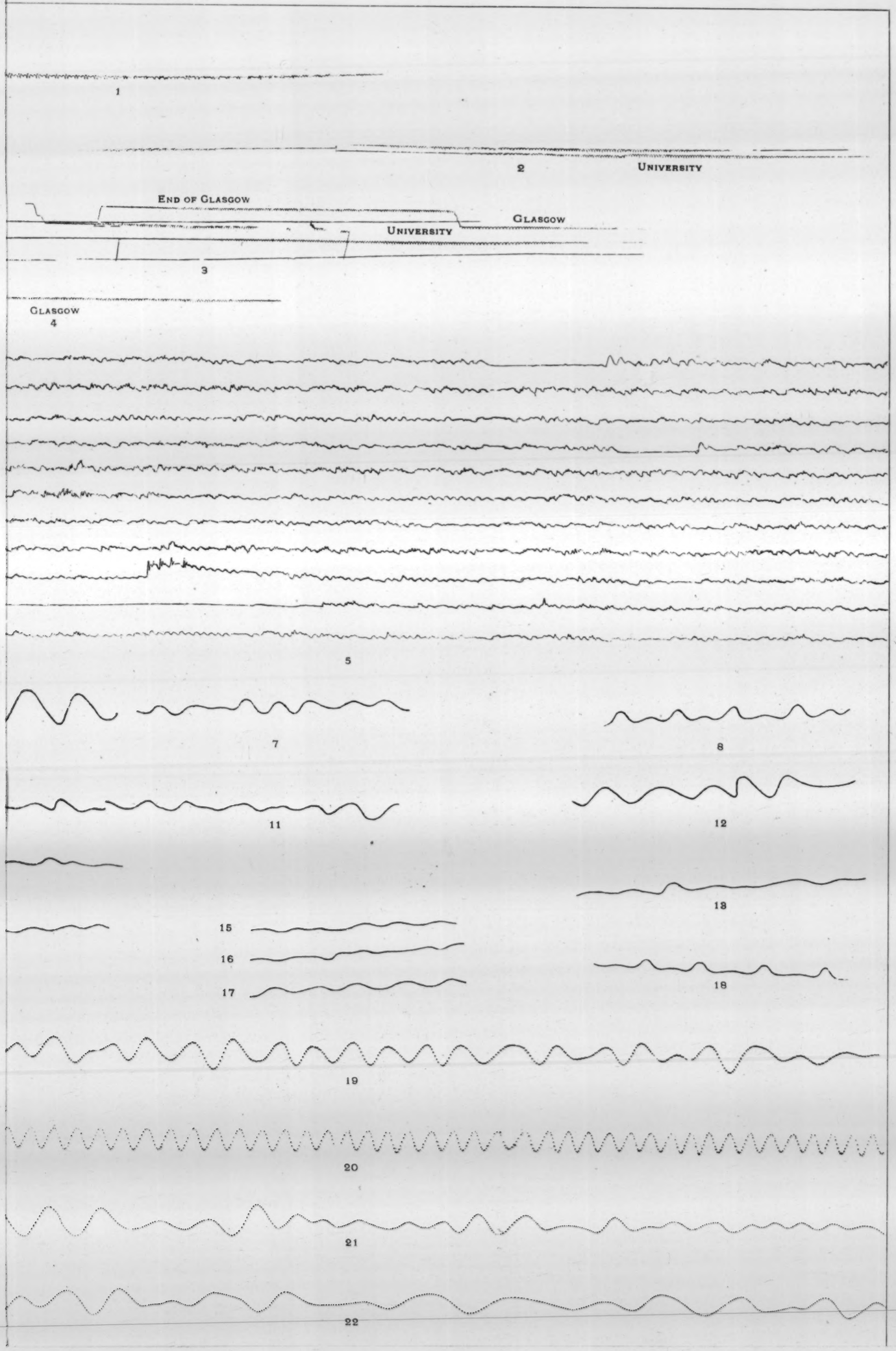
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XXIII.—*On the Genus* Anaspides *and its Affinities with certain Fossil Crustacea.*

By W. T. Calman, B.Sc., University College, Dundee. Communicated by Professor D'Arcy W. Thompson. (With Two Plates.)

(Read 18th May 1896.)

The genus *Anaspides* was founded in 1894* by Mr G. M. Thomson of Dunedin, New Zealand, for the reception of a very remarkable Schizopod Crustacean which he had discovered in a fresh-water pool at an altitude of 4000 feet on Mount Wellington in Tasmania. The very striking peculiarities of the animal, the absence of a carapace, the presence of plate-like gills attached to the bases of the thoracic legs, and the possession of an auditory organ in the peduncle of the antennules, led its discoverer to regard it as the type of a new family of Schizopods, the *Anaspidæ*, while suggesting that it might be entitled to "even higher specific rank." I have had an opportunity of examining three specimens of *Anaspides* presented to the Museum of University College, Dundee, by Dr Chas. Chilton of New Zealand, and from the dissection of one of these I have been able to supplement, in some important points, Mr Thomson's account of the external anatomy of the animal. I wish also to call attention to the remarkable resemblance, indicative I believe of close affinity, which *Anaspides* bears to certain Palæozoic Crustacea belonging to a group hitherto supposed to be unrepresented among living forms. The present paper has been prepared under the direction of Prof. D'Arcy W. Thompson.

MORPHOLOGY OF ANASPIDES.

Body.—When Mr Thomson describes *Anaspides* as possessing eight free thoracic segments, he makes no mention of the extreme interest and importance which would attach to such a state of things. In no living Malacostracan, save *Nebalia* and certain Stomatopods, do we find more than seven segments of the thorax completely defined, the segment corresponding to the first pair of maxillipeds being fused with the head even where, as in the *Edriophthalmata*, there is no other trace of a carapace. Mr Thomson's comparison of the body of *Anaspides* with that of an Amphipod would not therefore be strictly tenable, since, on his own showing, there is a difference in the number of segments. We believe, however, that this anomaly does not exist, and that *Anaspides* in this respect forms no exception to the rule among *Malacostraca*. Careful examination shows that the line which, in Mr Thomson's figure, marks off the "first

* *Trans. Linn. Soc. Zool.* (2), vi. 3. A preliminary account, without figures, was published in *Proc. Roy. Soc. Tasmania*, 1892.

thoracic" segment from the head, does not correspond to a movable articulation like those which separate the other segments of the body, but to a superficial groove in the integument (Plate I. fig. 2, *c*). That this groove does not represent the line of junction of the first thoracic segment with the head is, we think, shown by the fact that, instead of passing directly downwards on each side, parallel to the hinder margin of the segment, it runs obliquely forwards and ends just behind the root of the mandible, so that between it and the posterior border of the segment is included the region of the two pairs of maxillæ in addition to that of the maxillipeds (Plate I. fig. 1). Mr THOMSON's "first thoracic segment" must represent, therefore, the fused segments corresponding to these three pairs of appendages. Further, the position of this groove is precisely that of the "cervical sulcus," which, in the *Mysidæ*, crosses the carapace immediately above the mandibles, and with this sulcus it must, we think, be identified. And, as there is no reason to suppose that the cervical sulcus of the *Mysidæ* is other than the representative of the cervical groove of the Decapods, we are led to the presumption that the segments bearing the two pairs of maxillæ are morphologically posterior to this groove in the Decapods also, a presumption against which no anatomical evidence appears to militate. And if all this be true, we should then perceive the existence alike in *Anaspides*, in the *Mysidæ*, and in the Decapods, of a primary sulcus delimiting an anterior region or head to which three pairs of appendages, antennules, antennæ, and mandibles belong, the region in fact of the three paired appendages of the Nauplius, the "primary head region" of the Crustacea according to CLAUS.*

From this cervical groove in *Anaspides* there runs back on each side a horizontal line (fig. 2, *a*) which marks off inferiorly a quadrilateral area. Just behind the cervical groove a faint impressed line can be traced (fig. 2, *b*), for the most part nearly parallel with the main groove, but bending backwards for a short distance in the dorsal region, and terminating on each side near the junction of the horizontal line with the cervical groove.

While unable to suggest any definite interpretation of these various markings, we may note that Mr THOMSON's comparison of the horizontal line with that which marks off the "epimeron" on the thoracic segments of various *Isopoda* seems to be quite untenable. The "epimeron" in that group represents the coxal joint of the leg, and it is never marked off on the first thoracic segment, which in the *Isopoda* is indistinguishably fused with the head.

On the dorsal surface of the cephalic region, a short distance in front of the cervical groove, a small ill-defined area is more darkly pigmented than the surrounding parts, appearing to the naked eye as a distinct dark brown spot. In the centre of this area there is a clear, refractile, circular spot, surrounded by four smaller dots equidistant

* This suggestion deals with the morphology of the carapace only in so far that it leaves out of account the many complex issues that might arise from a full consideration of the various minor grooves, other than the main cervical one, which are described by BOAS (*Decap. Slaegtskab., Vidensk. Selsk. Skr.*, 1880) as present on the carapace of various Decapods.

from each other (fig. 2, *oc*). The appearance of these structures suggests at once that we have here to do with a group of ocelli. We cannot say positively, however, whether this is the case, since an attempt to ascertain by sectioning the structure of the organs was frustrated by the bad state of preservation of our material. There appears, however, to be no lenticular thickening, but rather a thinning away of the chitinous cuticle over the central spot, while the small lateral spots correspond to pits or actual perforations of the cuticle, and may possibly be merely the points of insertion of setæ which have been destroyed in the specimens examined. Whatever may be the nature of these or of the central spot, whether they be ocelli, as their appearance suggests, or not, we know of no structure in any adult Malacostracan with which they are comparable. Their position corresponds roughly with that of the "neck gland" of the Phyllopods, which has been identified with the embryonic "dorsal organ" of certain Malacostraca (*Edriophthalmata, Mysidæ*, &c.), but in the absence of further information as to their structure, it is impossible to guess what the meaning of these remarkable "ocelli" may be.

Antennules.—We have little to add to Mr THOMSON'S description of these organs. We can confirm his account of the auditory organ which is lodged in the first joint of the antennule and opens to the exterior by a narrow slit on the upper surface near the anterior end of the joint (fig. 2, *e*). The possession of an auditory sac in this position has hitherto been regarded as characteristic of the Decapoda, and its presence in *Anaspides* is, therefore, a point of great interest. CLAUS has suggested, in connection with his discovery of paired otocysts in the head of certain *Amphipoda* (*Oxycephalus*), which he regards as probably homologous with the auditory organs of the *Decapoda*, that the possession of such organs in the region of the head was a character of the primitive *Malacostraca.** The discovery of the auditory organs of *Anaspides* certainly lends considerable support to this view. In the male the inner flagellum of the antennule is modified in a very remarkable manner. The proximal joints of the flagellum are swollen and distorted, and armed with stout curved serrated spines. While we are as yet completely ignorant of the habits of *Anaspides*, we may hazard the conjecture that this modification of the antennules in the male is suggestive of a prehensile function rather than the sensory one which Mr THOMSON attributes to them. A modification of the antennules for such a purpose, common enough among the *Entomostraca*, would be almost if not quite unique among *Malacostraca*.

Antenna.—The peduncle of the antenna presents only two joints below the origin of the scale or exopodite, agreeing in this respect with the antenna of *Euphausiidæ*, and differing from that of the *Mysidæ*, where three joints are present. The peduncle of the flagellum, or endopodite, is also remarkable in possessing only two joints (for we do not find the short third joint figured by Mr THOMSON) in place of the three joints usual among the *Malacostraca*.

* ". . . dass schon zu einer Zeit, in welcher die Edriophthalmen- und Podophthalmenzweige noch nicht gesondert waren, vor dem Gehirn ein bläschenförmiges Sinnesorgan gelegen war, auf welches wir das Gehörorgan von Decapoden und Oxycephaliden zurückzuführen hätten."—CLAUS, *Crustaceen-System*, p. 27.

Mandible.—The body of the mandible (Plate I. fig. 3) is of the usual form, and carries a large three-jointed palp. The inner or cutting edge is divided into three regions, an anterior serrate (*a*), a posterior flattened (*c*) (the "molar process"), and a median (*b*), fringed with setæ, and separated from the anterior by a deep, and from the posterior by a shallow, notch. We have not only in the *Mysidæ* (Plate I. fig. 5) but throughout all the divisions of the Edriophthalmate Crustacea a somewhat similar three-fold division of the mandibular tomial edge, although the setæ fringing the median lobe in *Anaspides* are represented in these forms by a smaller number of comparatively large spines, while an accessory cutting blade (*lacinia mobilis* of Hansen), unrepresented in *Anaspides*, is commonly developed. The mandible of the *Euphausiidæ* (Plate I. fig. 4), on the other hand, is very different and comparatively simple. The median division is absent, and the serrations of the anterior part merge with the posterior molar process. This type of mandible, which is regarded by Boas* as the most primitive, seems more easily interpreted as a modification in the direction of simplification of the three-lobed type. This view is supported by Sars'† observation that the early larvæ of the *Euphausiidæ* have mandibles of a more complex type, resembling those of the *Mysidæ*. It seems probable, therefore, that the mandible of *Anaspides* belongs to a more primitive type than either the more complex organ of the *Mysidæ* or the apparently simple one of the *Euphausiidæ*.

The lower lip (labium or paragnatha) presents the general features of a bilobed plate with divergent lobes connected with each other for only a short distance at the base. It is chiefly remarkable for its large size, in which respect it even exceeds the exceptionally large dimensions of that organ in the *Euphausiidæ*. In connection with the large size of this organ, together with the apparent absence of an inner lobe associated with the first joint of the first maxillæ, it may be worth while to recall Claus' suggestion‡ that the two halves of the labium (or paragnatha) represent the said missing portions of the maxillæ.

First Maxilla (Plate I. figs. 6 and 6*a*).—We are able to add some details of importance to the somewhat brief description of this organ given in the original paper. The two lobes (*lacinia interna* and *externa* of Boas) are large, and directed somewhat forwards as well as inwards. The distal lobe is armed with stout toothed spines, and the proximal with feathered setæ. With the proximal lobe is connected an outwardly turned, rounded lobe (fig. 6, *ex*), not projecting beyond the outer edge of the maxilla, and lying closely adpressed to, though separate from, its posterior face. This outer lobe corresponds to the structure which in the first maxilla of other Schizopods (figs. 7 and 8) is usually regarded as the exopodite, but which Hansen§ regards as a process of the first joint of the limb. On the outer edge of the maxilla, somewhat on the anterior face, and about level with the division between the two

* *Stud. ü. d. Verwandschaftsbeziehungen d. Malakostraken. Morph. Jahrb.*, viii., 1882.
† *Challenger Rep.*, "Schizopoda," p. 153.
‡ *Neue Beiträge z. Morph. d. Crust. Arb. a. d. Zool. Inst. Wien*, vi., 1886, p. 15.
§ *Dijmphna Togtet Krebsdyr*, pp. 69–71. *Resumé*, p. 22.

inner lobes, is placed a prominent, outwardly directed papilla (figs. 6 and 6*a*, *p*), which from its position is evidently a rudimentary palp. Two distinct articulations can be recognised in the basal part of the outer edge of the limb (fig. 6, 1 and 2), marking off two plates which correspond to those in the first maxilla of *Euphausiidæ* (Plate I. fig. 7, 1 and 2), identified by HANSEN (*l.c.*) as representing the first and second joints of the limb.

While agreeing in general structure with the corresponding appendage of *Euphausiidæ* (fig. 7), the first maxilla of *Anaspides* differs in the rudimentary state of the palp and in the small size of the "exopodite." In both of these characters it approaches the first maxilla of the *Mysidæ* (Plate I. fig. 8), in which the palp is absent, and the "exopodite" is reduced to a prominent ridge on the outer edge of the limb.

Second Maxilla (Plate I. fig. 9).—On the outer border of the limb, the exopodite or flabellum, which is so prominent a feature in other Schizopods, vanishes, though we may perhaps interpret as representing it that portion of the outer border which is fringed with short setæ. Apart from this difference, the structure of this limb is easily reducible to the type of the *Mysidæ* (Plate I. fig. 11), if we suppose the compression of the forwardly turned lobes to be carried so far that the lobes come to lie nearly at right angles to the plane of the limb. As in the *Mysidæ*, there are three lobes internal to the palp, the innermost being continued backwards, forming the straight inner edge of the maxilla. The palp, which in the *Mysidæ* consists of two joints, presents here, as in the *Euphausiidæ* (Plate I. fig. 10), only one. The palp and the outermost of the three lobes carry peculiar comb-like setæ, which have been figured by Mr THOMSON. The chitinous framework of the second maxilla presents a complex structure which we have not been able, from the material at our disposal, to elucidate completely. A point of some interest is the presence of a distinct segment corresponding to the outer or distal lobe, the fourth segment of HANSEN, which, according to that author, is absent in the second maxilla of *Mysis*.*

Thoracic limbs.—The thoracic limbs are remarkable for the powerful development of the endopodites, which are obviously more efficient walking-legs than those of most Schizopods. In this respect they approach the corresponding appendages of the *Lophogastridæ*.

The first thoracic limb or maxilliped (Plate II. fig. 12) presents a complicated and very peculiar structure. The first joint or coxa is very large, and carries on its external face two appendages, the branchial lamellæ (fig. 12, *ep*), each consisting of a very small basal joint and an elongated lanceolate compressed lamina. On its inner face the coxa is produced into *two* flattened setose lobes (fig. 12, *en*) (not *three*, as shown in THOMSON'S figure). Of these the distal is the larger, expanding from a narrow neck to a somewhat triangular plate, and densely setose on the posterior face. The proximal is smaller, rounded, and fringed with setæ at the tip. Both lobes are articulated to the coxa in such a way as to allow a limited amount of movement,

* HANSEN, *Dijmphna Togtet Krebsdyr*, p. 70.

and in the natural position they are turned forward so as to oppose the posterior face to the corresponding part on the other side. The second joint or basipodite is very small, and carries on its outer face the exopod, which in the limb under consideration is short, and indistinctly or not at all segmented. The third joint or ischium is long, compressed, and thinned away toward the inner edge, which is somewhat produced and fringed with setæ. The basipodite is followed by *five* distinct joints, so that the main axis of the limb presents one more than the normal number of seven joints. Such an increase in the number of joints is not found elsewhere in the case of the maxilliped, though the number seven may be exceeded in the posterior thoracic limbs from the third onwards in various *Mysidæ*. The last joint is very small, and bears a number (about four) of stout curved spines.

The succeeding limbs, while agreeing in general form with the maxillipeds, present certain modifications in detail. The second pair (Plate II. fig. 13) lack the peculiar internal lobes which in the maxillipeds are borne by the coxal joint. The branchial lamellæ are much broader, ovate in shape, and their points of attachment are close together on the outer face of the coxa. The latter is very small, and partly fused with the third joint, from which, however, it is marked off by a distinct line. The exopodite is very large, and consists of an unjointed peduncle bearing a many-jointed, setose flagellum. The ischium is cylindrical, and not produced inwards to a cutting edge, as in the maxilliped. The third, fourth, and fifth pairs of thoracic limbs agree precisely with the second, save that the line of demarcation between the second and third joints becomes less distinct as we go backwards, while in the sixth pair the fusion of these two joints is complete, and the exopod appears to spring from the ischium. In the seventh pair of thoracic legs the exopod is reduced to a short unjointed lobe, and the branchial lamellæ are reduced in size. In the last pair of thoracic legs all these appendages are wanting, and the limb is only represented by the endopodite.

As regards the branchial lamellæ or epipodites, the possession by each limb of two is a most striking and important feature. In no other adult Crustacean do we meet with such a character as these two separate epipodites. They are completely separate from one another, and in the maxilliped a wide interval occurs between their origins. Thomson has suggested that these structures may be comparable to the epipodite of the *Euphausiidæ*, which, in the course of development, is at first bifurcate, but their arrangement in *Anaspides* does not suggest such a mode of origin, and it is important to note that on the maxilliped (where, in *Anaspides*, the two epipodites are most widely separate) the epipodite in the *Euphausiidæ* is always simple, it being branched only on the posterior limbs. There is, however, another possibility that suggests itself in connection with these epipodites. Claus has shown* that in the larvæ of certain *Penæidæ*, not only the podobranchiæ, but also the arthro- and pleurobranchiæ develop as outgrowths from the first joint of the legs, and he is inclined to regard the possession of three epipodial appendages as a primitive, if not primary, feature of the Malacostracan

* *Neue Beitr. z. Morph. d. Crust., Arb. Zool. Inst. Wien*, vi., 1886, pp. 42–45.

thoracic limb. It is accordingly conceivable that we have in *Anaspides*, more nearly than in any other Malacostracan, the primitive gills in primitive number and position. The same very learned carcinologist maintains* that the brood-plates of the *Edriophthalmata*, and of the *Mysidæ*, as well as the branchial plates of the *Amphipoda*, spring, in their first development, not from the inner but from the outer side of the limb, and are in fact epipodites. And we venture to suggest the possibility, or even likelihood, of the double epipodites of *Anaspides* representing the gills and brood-plates of the *Amphipoda*, to which, in their ovate flattened form, they are not destitute of a certain resemblance.†

The presence of two movably articulated lobes springing from the inner face of the coxa in the maxillipeds is a feature which, so far as we know, is without a parallel among the Malacostraca. A single simple lobe is developed in the same position in the *Euphausiidæ*, but not in the *Mysidæ*. In the latter, the joint corresponding to the coxa is small or rudimentary, but an internal lobe or lacinia springs in their case from the enlarged second joint. Somewhat similar processes are developed from the second and third joints of the maxillipeds in the *Edriophthalmata*. It seems not improbable that the presence of two pairs of lateral appendages, internal lobes and epipodial lamellæ, springing from the coxal joint of the maxilliped, may indicate that this joint represents the fusion of two joints. HANSEN‡ has given reasons for believing that the protopodite of the Crustacean limb is primarily three-jointed, not two-jointed as hitherto believed. The pre-coxal joint which he finds in *Nebalia*, and which, in the higher forms, is fused with the body, may possibly, in *Anaspides*, be fused with the coxal joint, and carry the proximal inner lobe of the maxilliped as well as the proximal epipodial lamella of that and the succeeding limbs.

Among minor features of interest in the thoracic legs of *Anaspides*, we note the reduction in size of the second joint, and its fusion with the third in the posterior members of the series. This joint is in the *Euphausiidæ* of much greater size, and in the *Mysidæ* attains, in the maxillipeds, an exaggerated development. Its fusion with the third joint has no parallel among the *Schizopoda*, but the same feature is found in the thoracic legs of many Decapods, especially in BOAS' group of *Reptantia*.

Another noteworthy point is the presence on the terminal joint of all the legs of a number (4–5) of stout curved claws. In the *Euphausiidæ* the terminal joint of the thoracic legs is tipped by a brush of setæ, while in most other Malacostraca the leg terminates in a single stout claw. *Anaspides* preserves for us a transitional stage between these two conditions, and it is interesting to note that, in the posterior thoracic legs, one of the claws exceeds the others very much in size, forming a further step in the direction of the "monodactyle" condition. With regard to the presence of eight joints in the thoracic legs, *Anaspides* may be compared with the Mysidan *Siriella*,

* *Op. cit.*, p. 34.

† The resemblance of the gill plates of *Anaspides* to those of *Amphipoda* is mentioned by Mr THOMSON in his preliminary paper, *l.c.*

‡ *Zool. Anz.*, xvi., 1893, p. 193.

where the same number of joints is attained in the posterior thoracic legs. HANSEN, indeed, regards the possession of eight joints in the thoracic legs as characteristic not only of the *Mysidæ*, but also of the *Cumacea* and *Edriophthalmata*, while in the *Euphausiidæ* and *Decapoda* only seven joints are recognised. *Anaspides* further resembles the *Mysidæ* and the other groups above associated with them in having the legs flexed at the articulation between the fifth and sixth joints instead of between the fourth and fifth as is the case in the *Euphausiidæ* and *Decapoda*.

Abdominal Appendages.—The first five pairs of abdominal appendages have the exopodite developed as a long, many-jointed flagellum fringed with setæ, and forming a powerful swimming organ. The endopodite of the third, fourth, and fifth pairs is a small rounded lobe, two-jointed, but without any trace of *appendix interna*. The endopodites of the first and second pairs are in the female similar to those of the succeeding pairs, but in the male they are considerably modified. In the first pair the endopodite has the form of a thick lobe, curved inwards and hollowed on its anterior face, and having near the distal end of its inner edge a rudimentary *appendix interna* carrying a tuft of short "coupling hooks" or *retinacula*. In their natural position the two endopodites of the first pair are turned horizontally forwards between the bases of the last pair of thoracic legs; they are united by the retinacula, and together constitute, in consequence of their curved and hollowed form, a shallow trough in which the endopodites of the second pair play. The latter are longer, two-jointed, the long first joint carrying a bunch of *retinacula* and a few spines near the tip. These appendages lie coupled together within the groove formed by the first pair of endopodites, and between them and the sternal surface of the thorax. In short, these first and second abdominal appendages occupy much the same mutual position in the male *Anaspides* as they do in the male Crayfish. Among the Schizopods, the *Euphausiidæ* alone agree with *Anaspides* in the circumstance of the two anterior abdominal appendages being modified in the male, but no very close comparison is possible between the structures seen in *Anaspides* and the elaborate system of lobes, hooks, and stylets which differentiate these organs in the *Euphausiidæ*.

The sixth pair of abdominal appendages or uropods form with the telson a tail-fan of the characteristic podophthalmate form (Plate II. fig. 14). Both exopodite and endopodite have a slight median keel, and the exopodite is crossed a little beyond the middle of its length by a transverse suture which, starting from the outer edge, reaches to within a short distance of the inner edge.

The telson is less than half the length of the inner plates of the uropods, rounded at the end, which is fringed with spines.

SYSTEMATIC POSITION OF ANASPIDES.

If we are content to deal with the generally recognised limits and definitions of the Crustacean groups, and if we acknowledge the commonly but not uni-

versally accepted association of *Euphausiidæ* with *Mysidæ* and their allies in the group *Schizopoda*, it is manifest, then, from the leading characters enumerated above, that *Anaspides* deserves to be also included in the *Schizopoda*, as it has been by its discoverer. But while we are content to place it so, its admission vastly increases the extent and importance of that group, for *Anaspides* stands far remote, within the group's now extended boundaries. The precise rank which we are to assign to it among the other members of the *Schizopoda* depends on the view we take as to the relations of these to one another. The commonly accepted classification of SARS * divides the sub-order *Schizopoda* into four families, *Lophogastridæ*, *Eucopiidæ*, *Euphausiidæ*, and *Mysidæ*, to which Mr THOMSON has added a fifth, *Anaspidæ*, for the reception of the genus under consideration. But the equivalence of these families is open to doubt, and some authorities have even denied the natural character of the group *Schizopoda* itself. BOAS † has proposed to break up the *Schizopoda* into two orders, *Mysidacea* (including the *Mysidæ*, *Lophogastridæ*, and *Eucopiidæ* of SARS) and *Euphausiacea* (*Euphausiidæ* of SARS), which he regards as not more nearly related to each other than they are respectively to the adjacent orders *Isopoda* and *Decapoda*. This dismemberment of the *Schizopoda*, which is also advocated by HANSEN, ‡ and adopted by ORTMANN, § has not been generally followed, but it must, we think, be recognised that it indicates the chief natural line of division among the organisms composing the group. This is the view taken by GERSTAECKER, ‖ who divides the *Schizopoda* into two tribes, *Holotropha* and *Hemitropha*, corresponding respectively to the orders *Mysidacea* and *Euphausiacea* of BOAS. Taking, then, the Mysid and the Euphausid as the two great types of *Schizopoda*, the points in which *Anaspides* approximates to one or other may be summarised as follows: the presence of only two joints in the peduncle of the antennæ, the characters of the first maxilla, the comparatively slight differentiation of the maxilliped from the rest of the thoracic limbs, the probable absence of a brood pouch, the presence of well-developed swimmerets in both sexes, and the modification of the first two pairs in the male, are all characters which incline towards the Euphausid type. With the exception of the first and last, we may look upon all these as points in which the Euphausid is more primitive and less differentiated than the Mysid type. On the other hand, the characters of the mandible and of the second maxilla resemble the Mysid rather than the Euphausid type, though not very closely comparable with either. The number of joints and mode of flexure of the thoracic legs are those of the *Mysidæ*, and we may also recall in this connection the fact that the carapace, the want of which is the most striking feature of *Anaspides*, is less strongly developed in the *Mysidæ*, where it leaves five of the thoracic segments free, than in the *Euphausiidæ*, where it is fused with all except the last. But besides the characters that permit us to acquiesce in its status as a Schizopod, the singular interest attaching to *Anaspides* is not diminished, and the difficulty of comprehending it is much increased by the coincident presence

* *Challenger Rep., Schizopoda.* † *Morph. Jahrb.*, viii., 1882. ‡ *Zool. Anz.*, xvi., 1893, pp. 202–5.
§ *Plankton Exp., Decapoden u. Schizopoden.* ‖ BRONN'S *Klassen u. Ordn. d. Thierreichs, Arthropoda.*

of several important characters which point, as it were, in various directions towards presumably far distant branches of the Crustacean stem. Its auditory organs are those of a Decapod, the general form of the body is more that of an Amphipod than a Schizopod, while such characters as the double epipodial lamellæ, the coxal lobes of the maxilliped, and the remarkable dorsal "ocelli" (if such they be) are without parallel among the *Malacostraca*.

COMPARISON WITH PALÆOZOIC FORMS.

But *Anaspides* becomes still more striking in its interest when we pass from the limits of the recent fauna to seek comparisons with fossil forms. Among Palæozoic Crustacea there are several forms whose systematic position has hitherto been a complete puzzle to palæontologists. The genera associated together by PACKARD to form the groups *Syncarida* and *Gampsonychidæ* agree with each other and with *Anaspides*, and together with it stand apart from all other Crustacea whatsoever, in combining with the absence of a carapace, the presence of distinctly podophthalmate characters in antennules, antennæ, and tail-fan. These fossil forms had been compared by various palæontologists with the *Amphipoda*, the *Isopoda*, and the *Macrura*, while PACKARD emphasised more particularly their affinities with Schizopods. With this preliminary statement we pass to a detailed comparison of *Anaspides* with the Palæozoic genera.

PALÆOCARIS.

Palæocaris typus was first described in 1865, by MEEK and WORTHEN, from the Coal Measures of Illinois.* PACKARD, in 1886,† redescribed the species, and gave a restoration, which we reproduce (Plate II. fig. 15), certain characters being added from a later paper by the same author.‡ It is manifest from the figure that *Palæocaris* resembles *Anaspides* in general shape. The body is uniformly segmented, there being seven distinct segments in the thorax, while a carapace is completely lacking. The first five abdominal segments carry downwardly projecting pleura, the sixth segment being elongated and apparently cylindrical. The eyes are unknown, but the antennules have the three-jointed peduncle strongly developed and carrying a pair of flagella, of which the longer is one-third or one-half the length of the body. The antennæ have a broad scale or exopodite, extending nearly to the end of the peduncle, rounded at the end, and edged with setæ. Two joints of the peduncle are seen, and the flagellum is as long as the body. Of the thoracic appendages only six pairs are shown in the restoration, but it is stated in the text that the first two pairs in front of these are "gnathopods like those of existing Schizopods, especially *Petalophthalmus*," though

* *Proc. Acad. Nat. Sc. Philadelphia*, 1865 ; also, *Rep. Geol. Survey, Illinois*, iii., 1868.

† *Mem. Nat. Acad. Sci. Washington*, iii. (2), 1886. A preliminary abstract in *Amer. Naturalist*, xix., pp. 790–792, 1885.

‡ *Proc. Boston Soc. Nat. Hist.*, xxiv., pp. 211–213, 1889.

the grounds for this statement are neither specified nor obvious. Each of the thoracic legs bears at its base an appendage about one-half as long as the limb itself, and nearly twice as broad, bluntly pointed at the tip, and indistinctly divided into three joints. PACKARD, in his preliminary communication, describes these as "breeding lamellæ," but in his later paper he withdraws this interpretation, and states that these appendages are to be regarded as "endopodites." What is meant by this use of the term endopodite we cannot understand, and the matter is made no clearer by PACKARD's reference to the "large ovate-lanceolate endopodites" of *Petalophthalmus*, for these can be no other than the brood-lamellæ themselves. In PACKARD's figures, what is apparently the main axis of the limb is lettered as the exopodite, but no explanation is given of this remarkable departure from ordinary nomenclature. The position of these so-called "endopodites" suggests that they correspond to the natatory exopodites of Schizopods, but they seem to differ very strikingly in shape from the slender, many-jointed exopodites usual in that group. An alternative hypothesis in regard to their homology is suggested by the resemblance of these organs in *Palæocaris* to the epipodial lamellæ of *Anaspides*, and more particularly to those of the maxilliped. This suggestion is founded partly on these considerations of size and appearance, further on the ground that a remarkable agreement has been shown to exist between *Palæocaris* and *Anaspides* in regard to other very important characters, and, lastly, on the ground that true exopods might very likely have perished in the fossil were they, as it is not unreasonable to suppose they were, similar either to those of the true Schizopods or of *Anaspides* itself; there can, indeed, be no strong presumption of their absence from *Palæocaris* in view of the many small and fragmentary structures that evidently lie entangled in this portion of the fossils. On this view, the single articulation at the base of each gill-lamella in *Anaspides* might conceivably be taken as the vestige of a segmentation formerly present in these organs, and partially preserved in *Palæocaris*.

The first five pairs of abdominal appendages in *Palæocaris* are powerful swimmerets, consisting each of a stout peduncle carrying "probably two slender rami," though only one is shown in the figure. The sixth pair form, with the telson, the usual tail-fan (fig. 15*a*). The outer plate or exopodite has a longitudinal median ridge, the homologue of which is to be recognised in *Anaspides*, and as in that form a transvere suture crosses the exopodite near the tip. The inner plate or endopodite is shorter than the outer, but longer than the telson, which is rounded at the tip and edged with setæ. PACKARD states that "there are traces of a pair of abdominal legs to each of the *seven* segments," but we may be permitted to doubt the existence of so extraordinary a deviation from the ordinary structure of the Malacostraca.

Particular interest attaches to the statement that the head of *Palæocaris* "is apparently composed of two segments." In the original figure of MEEK and WORTHEN there is no trace of this, but in PACKARD's restoration a line running downwards and backwards on the side of the cephalic region cuts off a wedge-shaped segment. The direction of this line is very different from that which we have called the cervical groove

in *Anaspides*, but as it seems to have been only imperfectly visible on the fossil, it is possible that the restorer was guided to some extent in this point by the analogy of *Gampsonyx*, in which a similar line is very distinct.*

To sum up, *Palæocaris* resembles *Anaspides* closely in general form, in the number of free segments of the body, in the absence of a carapace, in the general characters of antennules and antennæ, of the swimmerets, and of the tail-fan. Points of doubtful agreement are found in the line which divides the two "segments" of the head, which may possibly represent the cervical groove of *Anaspides*, and in the so-called "endopodites" of the thoracic legs, which may correspond either to exopodites or to epipodial lamellæ, but which must be either one or other. Points of actual difference exist in the arrangement of the last-named organs, which, whatever their nature, are arranged in a single series, and are stated to be present on all the eight pairs of thoracic limbs, whereas in *Anaspides* both exopodites and gill-plates are absent from the last pair of legs. It is not improbable that some of these differences might be reduced, could the actual specimens of *Palæocaris* be re-examined in the light of the information afforded by *Anaspides*. PACKARD, throughout his papers, compares *Palæocaris* with the deep-sea *Petalophthalmus* and with no other Schizopod. Beyond the fact that the carapace in that very aberrant genus is unusually small, we do not see any indication of a special affinity between the two forms.

GAMPSONYX.

Gampsonyx fimbriatus, from the Coal Measures of Saarbrück,† was described by JORDAN and v. MEYER in 1854.‡ As will be seen from the figure (Plate II. fig. 17), it resembles *Palæocaris* in the segmentation of the body, but the line which in that genus divides the two "segments" of the head according to PACKARD is here more distinct, so that there appear to be eight free thoracic segments behind the head. It is very tempting to compare this with the condition found in *Anaspides*, but we have above given reasons for thinking that the so-called "first thoracic segment" in that form includes the region of the maxillæ as well as that of the maxillipeds. In the fossil form this does not appear to be the case, for the segment in question is narrower below than above, and would apparently correspond to only one pair of appendages.§ Still the coincidence in the number of apparent segments in the two forms is a very remarkable circumstance, and a re-examination of the fossils on this point is much to be desired.

The eyes of *Gampsonyx* are stated to be pedunculated. The antennules resemble those of *Palæocaris*. The antennæ have a large scale, rounded at the tip, a three-jointed peduncle, and a long flagellum.

* The *Palæocaris scoticus* of PEACH (*Trans. Roy. Soc. Edin.*, xxx., p. 85, pl. x. 3) differs very markedly from the American form in the arrangement of grooves on the head-region. It may possibly represent a distinct genus.

† These strata are now referred by some authorities to the Dyas.

‡ *Ueber d. Steinkohlenformation von Saarbrücken. Palæontographica*, iv., 1856.

§ JORDAN and v. MEYER remark that this segment varies slightly in length in different specimens.

From the region of the first or second segment behind the head there springs a stout limb which reaches beyond the peduncle of the antennules. Four joints are visible, and the last two are armed with stout spines which, on the last joint, seem to form a sort of pseudo-chela. PACKARD identifies this limb as a mandibular palp, which he compares with the enormously developed palp of *Petalophthalmus*. Apart from the fact that the mandibular palp of the Malacostraca never presents more than three joints, the base of this limb appears to be placed much too far back to correspond with the position of the mandible, and it is more probable that it represents the first or second thoracic leg. With reference to the other thoracic legs, PACKARD says that these, "irrespective of the endopodites, are represented as biramous, and the two rami are drawn as of nearly equal length. It is probable that there has been a mistake in drawing the legs, as in none of the existing Schizopods, such as *Mysis* and its allies *Euphausia*, *Gnathophausia*, *Petalophthalmus* or *Chalaraspis*, are the legs thus thrice divided." In the preliminary note the same passage occurs, but "breeding lamellæ" is substituted for "endopodites," which makes the last sentence still more obscure. As a matter of fact, the legs are shown in JORDAN and v. MEYER'S figure as bifurcating *near the tip*, in the region, apparently, of about the third last joint. This appearance is doubtless due, however, to the overlapping of the appendages of the two sides. A confused mass which covers the bases of the legs shows traces of what may have been exopodites, and may possibly involve also the remains of gills.* The abdomen carries well-developed swimmerets. The tail-fan is similar to that of *Palæocaris*; the outer plates are divided by a suture, and the telson is comparatively short and rounded. It is stated that the telson appears to be fused with the last segment of the abdomen. If this be so, the tail-fan will bear some resemblance to that of certain *Isopoda*, particularly of the *Gnathiidæ*.

Gampsonyx, then, while agreeing in general characters with *Palæocaris*, differs from it in two points. It possesses an apparently free first thoracic segment only obscurely indicated, if at all, in *Palæocaris*, and it has a pair of powerful raptorial limbs identified by PACKARD as mandibular palps, but more probably to be referred to the first or second thoracic limbs. Neither of these differences increase the resemblance with *Anaspides*, unless indeed the "first thoracic" segments of the two are homologous, which is very doubtful. The character of the limbs indicates that *Gampsonyx* is probably a somewhat more specialised development from the common stock to which both *Anaspides* and *Palæocaris* are related.

ACANTHOTELSON.

Acanthotelson was described in 1860 by MEEK and WORTHEN from the Coal Measures of Illinois. It was doubtfully referred to the *Isopoda* by these authors, who, however, noted its resemblances to the *Decapoda*. PACKARD has given a restoration (Plate II.

* "Ueberdiess erkennt man dass an der Wurzel der vordern sieben oder acht Füsse noch besondere Anhängsel vorhanden waren, und zwar von namhafter Länge und Stärke."—JORDAN and v. MEYER, *op. cit.*

fig. 16), and on his account alone the following remarks are based. In general shape *Acanthotelson* resembles the two genera which we have considered above, but the body appears to have been somewhat flattened dorso-ventrally. The head (fig. 16*a*) is stated by PACKARD to consist of two segments, but he continues:—"The second segment is distinctly separated by an impressed line from the first, but there is not a true articulation between them, so that the first and second cephalic segments may be said to be consolidated, and to represent the carapace of the *Schizopoda*." This account corresponds very closely indeed with the condition which we have described in *Anaspides*, although, as the line in question is not shown in the lateral view, we do not know whether its direction corresponds to that of the cervical groove in the last-named form. PACKARD describes the second segment as having "on each side a low, boss-like swelling, situated obliquely and prolonged in an oblique direction to the anterior outer edge." It is not impossible that the structure here referred to may represent the quadrilateral area which in *Anaspides* is cut off from the side of the cephalic region behind the cervical groove.

The eyes of *Acanthotelson* are unknown. The antennules have a three-jointed peduncle which carries two flagella. The peduncle of the antennæ is also three-jointed, and carries a moderately long flagellum. No antennal scales are shown in the figures, but traces of them are said to have been present, and in an allied form, placed by PACKARD in a separate genus, *Belotelson*, the antennal scales are said to be large, "resembling those of the *Macrura*."

Seven pairs of thoracic limbs are preserved, the first of these being very large, and armed with stout spines. The second pair are slightly enlarged, the following five pairs more slender and uniform in appearance. None of the thoracic limbs, so far as seen, are specialised as maxillipeds, and it is on this account, we presume, that PACKARD refers to them as "Schizopod-like," for no exopodites appear to have been observed.

The first five pairs of abdominal appendages in *Acanthotelson* are well-developed swimmerets, biramous, the exopodite being "lanceolate oval." PACKARD states that they resemble the corresponding appendages of *Squilla*, but elsewhere he states that they bear "a general resemblance to those of the Schizopoda."

The tail-fan is remarkable for the slender form of both branches of the uropods, as well as of the telson.

It will be seen from the above account that *Acanthotelson* resembles considerably the other two fossil forms which we have already considered. The spined raptorial limbs recall those of *Gampsonyx*, from which, indeed, the present form is mainly separated by the slender uropods and telson, and by the apparent absence of exopods from the thoracic limbs. We find no further hints of special affinity with *Anaspides*, save, perhaps, in the structure of the cephalic region, PACKARD'S description of which applies almost exactly to *Anaspides*.

PACKARD'S views as to the affinities of the above-mentioned genera are as follows:—

In the first place, *Acanthotelson* and the doubtfully distinct *Belotelson*, are made to constitute a sub-order *Syncarida* "standing near or at the base of the Thoracostraca, not far from the *Stomapoda* and *Schizopoda*, and with appendages closely homologous with those of these two groups." We find it difficult to see how such an homology could be simultaneously close with the limbs both of Schizopod and Stomatopod. Under the name *Gampsonychidæ* PACKARD unites the genera *Palæocaris* and *Gampsonyx*, ranking them as a family of the Schizopoda. The reasons for this marked difference in the systematic rank assigned to these two groups are not very clear, for while PACKARD enumerates the resemblances between the *Syncarida* and the *Gampsonychidæ*, he nowhere indicates what he considers as the essential distinctions between the two.* As a matter of fact, *Acanthotelson* approaches very closely indeed to *Gampsonyx*; so far as we can gather, the only fundamental difference between the two lies in the fact that the thoracic limbs of *Acanthotelson* are stated not to possess exopods. In view, however, of the uncertain indications of these organs in *Gampsonyx* and in *Palæocaris* it seems hardly safe to lay too much stress on their alleged absence from *Acanthotelson*. By other palæontologists the genera in question have been generally referred, on account of the absence of a carapace, to the *Edriophthalmata*. *Gampsonyx* is described by JORDAN and v. MEYER as an Amphipod with characters of the *Decapoda*, particularly of the *Macrura*, while *Acanthotelson* was placed by its discoverers among the *Isopoda*, and these views have been recently endorsed, though with an expression of doubt, by so high an authority as Dr HENRY WOODWARD.†

We find, then, that *Anaspides* agrees with the extinct genera above enumerated in the essential point in which they have hitherto stood alone: the combination of Podophthalmate characters with a completely segmented body and the lack of a carapace. We have seen that some at least—probably all—of these genera show characters of the *Schizopoda*, to which group *Anaspides* is most closely allied. We find probable agreement in such points as the apparent division of the head region into two segments as by the "cervical groove" in *Anaspides*. Such differences as have appeared are readily explicable as comparatively unimportant differentiations which might be expected to occur within the limits of the group, or as due to the present imperfect state of our knowledge of the fossil forms. We conclude, therefore, that *Anaspides* is to be regarded as the representative of a group of primitive *Malacostraca*, which had already, in Palæozoic times, attained a certain degree of specialisation and a very wide distribution.

* Apparently, however, PACKARD'S views on this point have been somewhat modified, for in the 5th edition of his text-book of Zoology, published in the same year (1886) as the papers above referred to he uses the term *Syncarida* as including *all* the genera above named.

† "Anniversary Address," *Proc. Geol. Soc.*, lii., 1896.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. *Anaspides tasmaniæ*, G. M. THOMSON. Male, enlarged 3½ diameters (from a photograph).
Fig. 2. Dorsal view of head region. *e*, opening of auditory sac; *o*, (supposed) "ocelli"; *c*, cervical groove; *a* and *b*, other grooves on integument (see text).
Fig. 3. Left mandible (palp omitted). *a*, *b*, and *c*, anterior, middle, and posterior (or molar) divisions of inner edge.
Fig. 4. *Boreophausia raschii*. Cutting edge of left mandible.
Fig. 5. *Mysis oculata*. do. do. *l.m*, *lacinia mobilis*.
Fig. 6. *Anaspides*. First maxilla of right side, posterior face.
Fig. 6*a*. Do. do. anterior face. *ex*, exopodite; *p*, palp; 1 and 2, first and second joints.
Fig. 7. *Boreophausia*. First maxilla of right side, posterior face.
Fig. 8. *Mysis*. do. do. do.
Fig. 9. *Anaspides*. Second maxilla of right side, posterior face. *p*, palp; 2, 3, and 4, lobes numbered according to HANSEN.
Fig. 10. *Boreophausia*. Second maxilla of right side, posterior face. *ex*, exopodite: *p*, palp.
Fig. 11. *Mysis*. Second maxilla of right side, posterior face. *ex*, exopodite; *p*, palp.

PLATE II.

Fig. 12. *Anaspides*. Maxilliped of left side, posterior face; *ex*, exopodite; *ep*, epipodial lamellæ; *en*, internal lobes of coxa.
Fig. 13. *Anaspides*. First walking leg of left side (second thoracic limb). *ex*, exopodite; *ep*, epipodial lamellæ.
Fig. 14. *Anaspides*. Tail-fan.
Fig. 15. *Palæocaris typus*, M. and W. Restoration (after PACKARD).
Fig. 15*a*. Do. do. Tail-fan (after PACKARD).
Fig. 16. *Acanthotelson stimpsoni*, M. and W. Restoration (after PACKARD).
Fig. 16*a*. Do. do. do. Dorsal view of head region, restored (after PACKARD).
Fig. 17. *Gampsonyx fimbriatus* (after JORDAN and v. MEYER).

NOTE.—Since the above paper was in type, we have received from Mr G. M. Thomson (to whom we are much indebted for valuable material in connection with the study of Australasian Crustacea), specimens of *Anaspides* from a new locality, "Lake Field, a spot 40 miles from Hobart, Tasmania, at an elevation of about 4000 feet." This altitude corresponds with that of the pools on Mount Wellington, where the species was originally discovered by Mr Thomson.

W. T. Calman on the Genus Anaspides — Plate I.

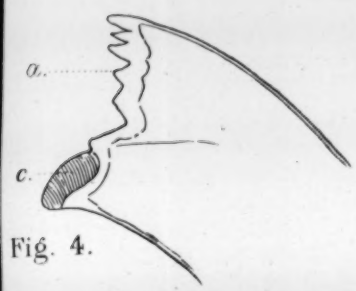


Fig. 4.

Fig. 5.

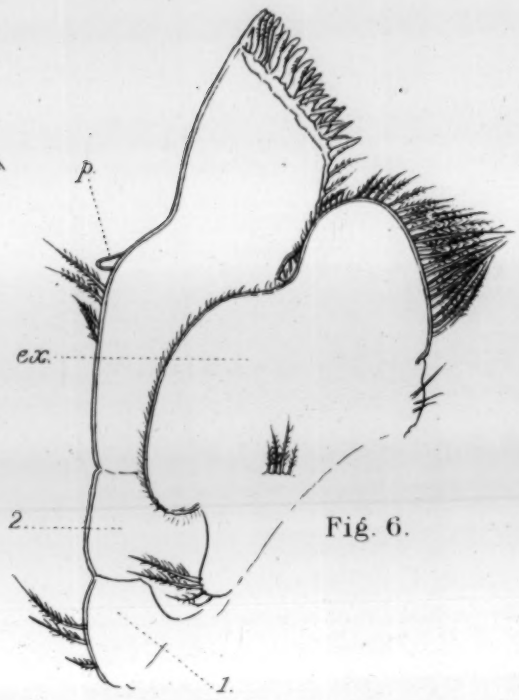


Fig. 6.

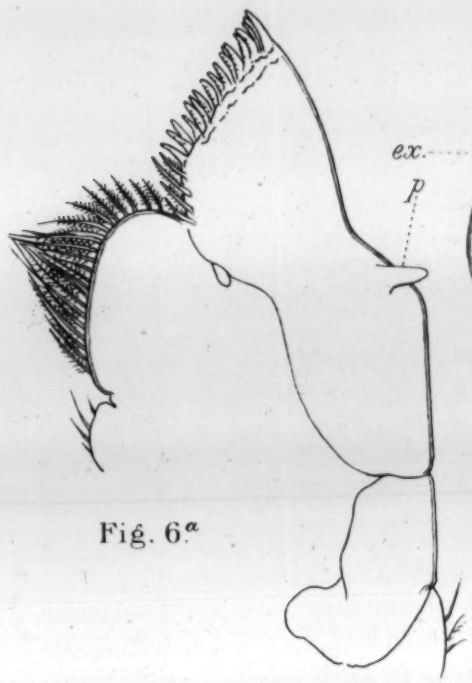
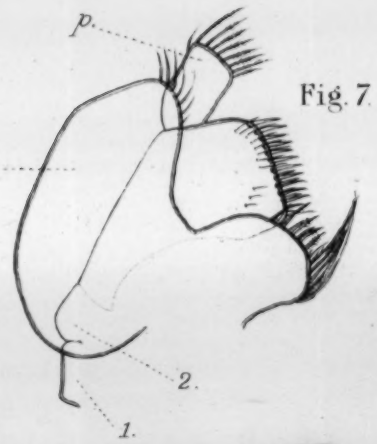


Fig. 6ª



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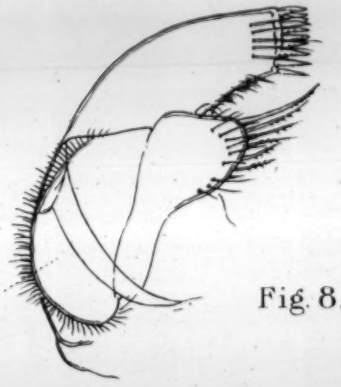


Fig. 8.

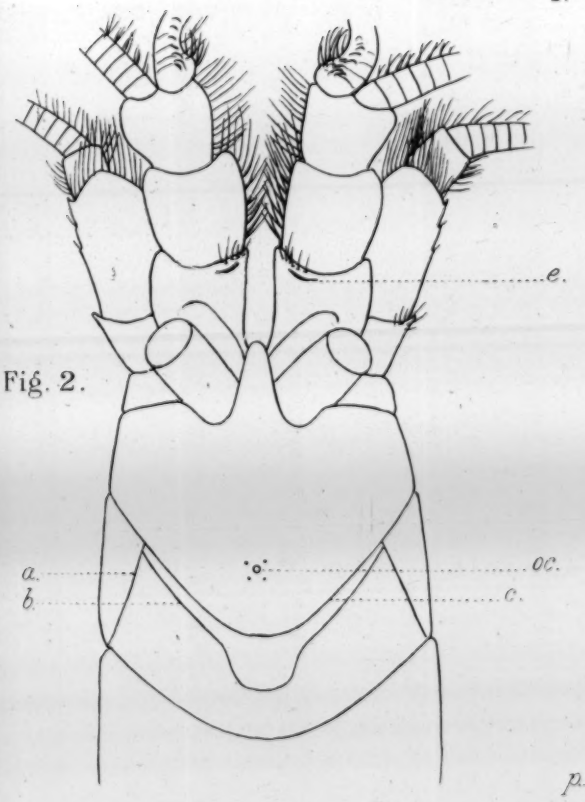


Fig. 2.

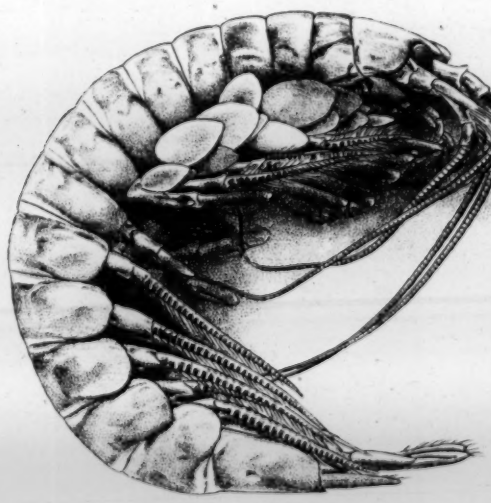
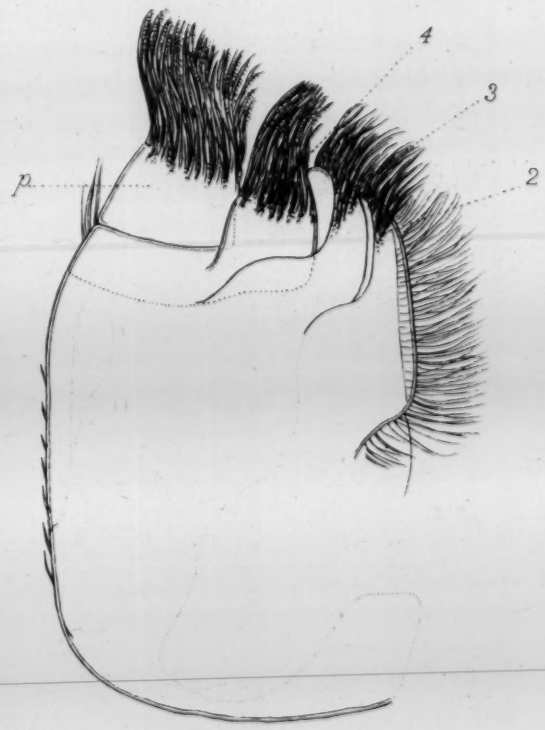


Fig. 1

Fig. 3.



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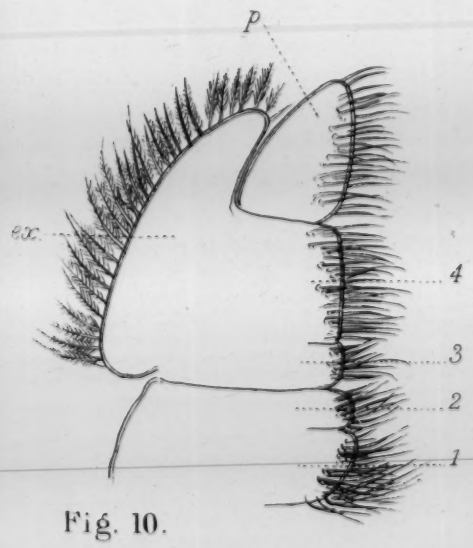

Fig. 10.

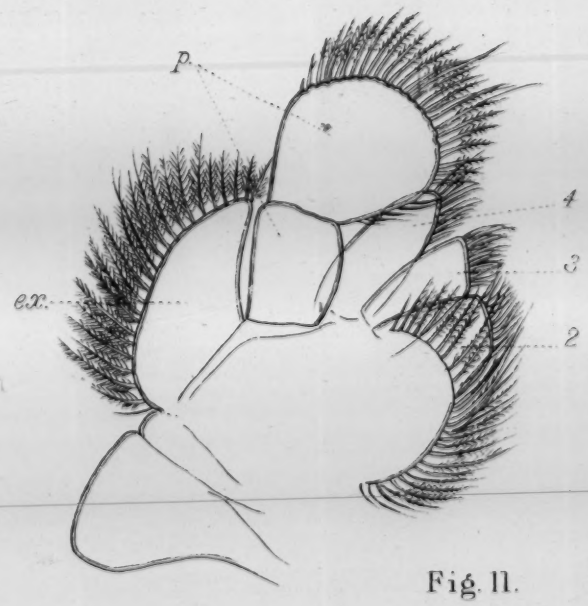

Fig. 11.

A. T. Calman, del^t

M^cFarlane & Erskine, Lith^rs Edin^r

W. T. CALMAN ON THE GENUS ANASPIDES — PLATE II.

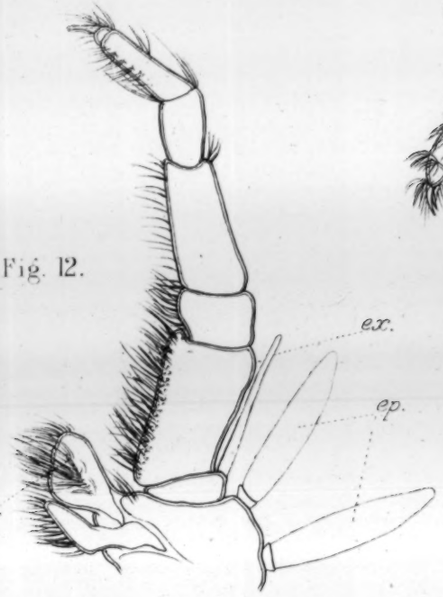

Fig. 12.

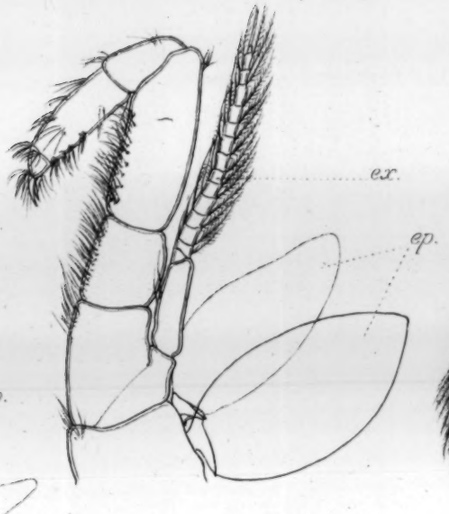

Fig. 13.

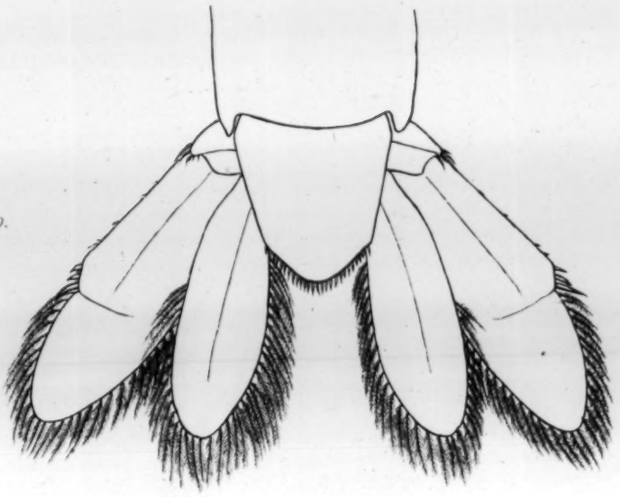

Fig. 14.

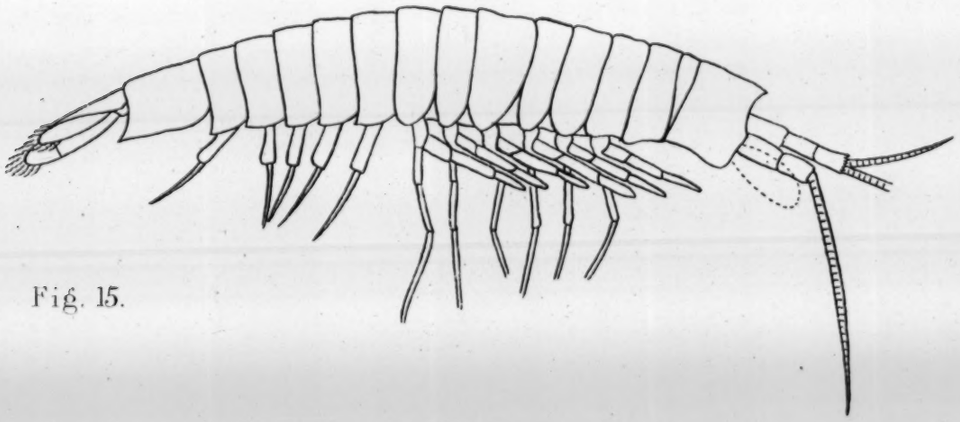

Fig. 15.

Fig. 15a

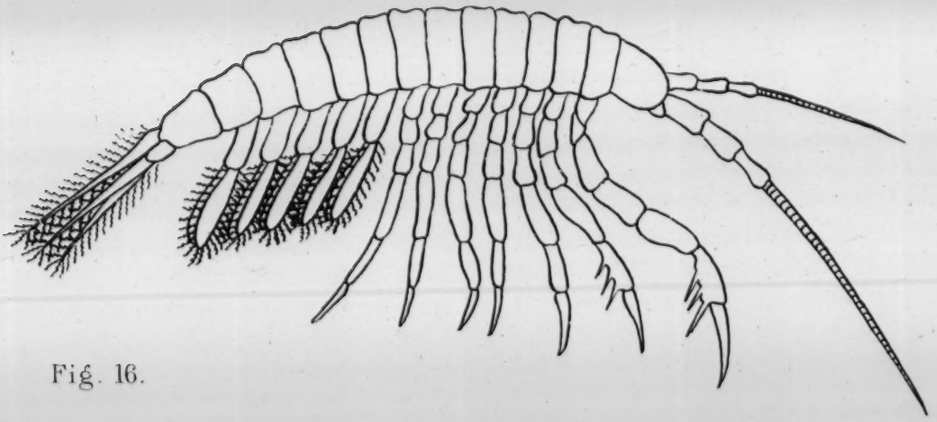

Fig. 16.

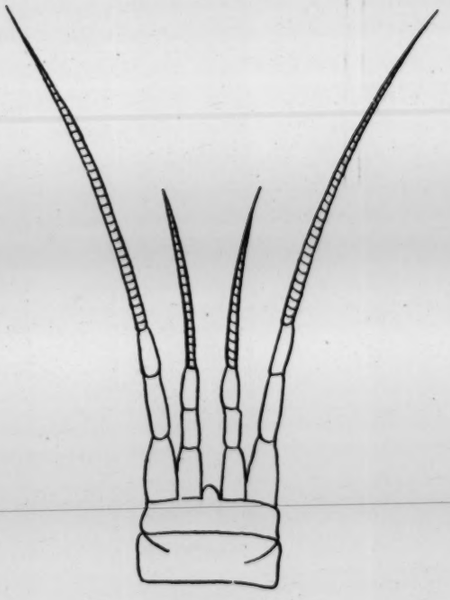

Fig. 16a

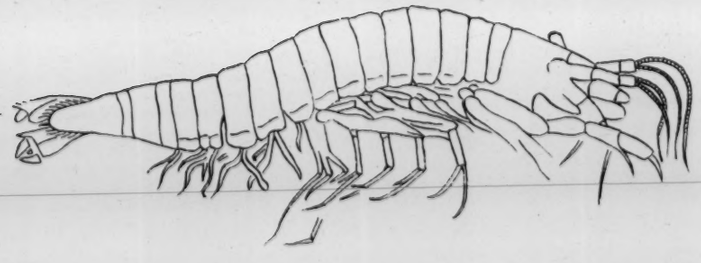

Fig. 17.

XXIV.—*On the* p*-discriminant of a Differential Equation of the First Order, and on Certain Points in the General Theory of Envelopes connected therewith.* By Prof. CHRYSTAL.

(Read 15th June 1896.)

The theory of the singular solutions of differential equations of the first order, even in the interesting and suggestive form due to Professor CAYLEY (*Mess. Math.*, ii., 1872), as given in English text-books, is defective, inasmuch as it gives no indication as to what are normal and what are abnormal phenomena. Moreover, CAYLEY added an appendix to his theory regarding the circumstances under which a singular solution exists, which is misleading so far as the theory of differential equations is concerned, if not altogether erroneous.

The main purpose of the following notes is to throw light on the point last mentioned by means of a number of examples. I have also taken the opportunity to furnish simple demonstrations of several well-known theorems regarding the p-discriminant which do not find a place in the current English text-books.

It may be premised that in what follows we shall regard only such integral curves of the differential equation at any point as admit of an approximate representation of the form

$$y=\lambda x^{\alpha}+\mu x^{\beta}+\ldots\ldots$$

where α, β, ... are commensurable numbers, *i.e.*, only integrals which have an 'algebraic point' at x, y.

Nature of the Integral of the Equation—

$$A_0+A_1p+A_2p^2+\ldots\ldots+A_np^n=0 \quad . \quad . \quad . \quad . \quad (1)$$

at a Point on the p*-discriminant Locus, in the most General Case.*

We suppose that at the point in question A_0, A_1, ..., A_n are synectic: so that we have

$$\left.\begin{aligned} A_0&=a_0+b_0x+c_0y+d_0x^2+\ldots\ldots,\\ A_1&=a_1+b_1x+c_1y+d_1x^2+\ldots\ldots,\\ A_2&=a_2+b_2x+c_2y+d_2x^2+\ldots\ldots,\\ &\ldots\ldots\\ A_n&=a_n+b_nx+c_ny+d_nx^2+\ldots\ldots. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (2).$$

We take the most general case, and suppose that two values of p, and no more, become equal at the point on the p-discriminant locus. Let this point be taken as

origin; and let the x-axis be the tangent to the integral curve of (1). Then, corresponding to $x=0$, $y=0$, (1) must have two zero roots, and no more. Hence $a_0=0$, $a_1=0$, $a_2\neq 0$. In the most general case the values of the other constants, b_0, c_0, &c., will be unrestricted, and the p-discriminant locus will not touch the x-axis.

If we confine ourselves to points infinitely near the origin, x will be an infinitely small quantity of the first order; y infinitely small, of second order at least; and p infinitely small, but not necessarily of the same order as x or y. (It will, in fact, be of the order $\alpha-1$, if α be the order of y, *i.e.*, of the same order as y/x.)

If we neglect in the equation (1) all quantities that are obviously not of the lowest order, we have in the most general case merely

$$b_0x+a_2p^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3);$$

the integral of which, subject to the condition $y=0$ when $x=0$, is

$$y=\pm\tfrac{2}{3}\left(-\frac{b_0}{a_2}\right)^{\frac{1}{2}}x^{\frac{3}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

Hence the integral curve of (1) has a cusp at the origin (fig. 1).

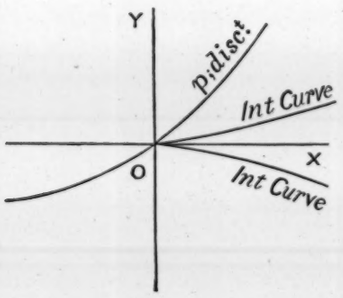

FIG. 1.

It follows that *the* p-*discriminant locus is in general the locus of cusps on the integral curves of the differential equation.*

On the Nature of the Integral at a Point on the p-*discriminant Locus where the Primitive in question touches that Locus.*

If we take the origin at the point in question and the tangent to the integral curve as x-axis, the differential equation will take the form

$$b_0x+c_0y+d_0x^2+(b_1x+c_1y)p+a_2p^2=0 \quad . \quad . \quad . \quad . \quad (1),$$

where all terms have been omitted which will obviously not be ultimately required for our approximations.

The p-discriminant is given by combining (1) with

$$b_1x+c_1y+2a_2p=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

and regarding p as an arbitrary parameter For all points with which we are concerned the value of p is small.

Eliminating p, we have, therefore, for an approximation to the p-discriminant near the origin

$$b_0x+c_0y+d_0x^2-\frac{1}{4a_2}(b_1x+c_1y)^2=0 \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Hence the tangent to the p-discriminant at the origin is $b_0x+c_0y=0$.

The necessary and sufficient condition that the primitive touch the p-discriminant at the origin is therefore

$$b_0=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

The equation to the p-discriminant now reduces to

$$c_0y+d_0x^2-\frac{1}{4a_2}(b_1x+c_1y)^2=0 \quad . \quad . \quad . \quad . \quad . \quad (5),$$

wherein the term d_0x^2 cannot now be neglected. To the present order of approximation (5) may be written

$$\left.\begin{aligned} y&=\frac{b_1^2-4a_2d_0}{4a_2c_0}x^2 \\ &=kx^2, \text{ say.}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (6).$$

The differential equation reduces to

$$c_0y+d_0x^2+b_1xp+a_2p^2=0 \quad . \quad . \quad . \quad . \quad . \quad (7).$$

If we assume the approximation

$$y=\lambda x^a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

for the solution of (7), we get

$$a^2a_2\lambda^2x^{2a-2}+(ab_1+c_0)\lambda x^a+d_0x^2=0 \quad . \quad . \quad . \quad . \quad (9),$$

where $a_2\neq 0$, and *in the general case* $d_0\neq 0$.

Now $2a-2>=<a$, according as $a>=<2$. Hence, if $a<2$, we have $2a-2<a<2$; and, if $a>2$, $2a-2>a>2$. Since $a_2\neq 0$, and $d_0\neq 0$, neither of these hypotheses leads to an approximation.

We must therefore have $a=2$, and

$$4a_2\lambda^2+(2b_1+c_0)\lambda+d_0=0 \quad . \quad . \quad . \quad . \quad . \quad (10).$$

In general (10) will have two distinct roots; and we conclude that *in general, when the primitive touches the* p-*discriminant two integral curves touch each other there, and we have a tac-point.*

If a branch of the integral curve touch the p-discriminant at *every* point of the latter, and *not merely at a single point*, as hitherto supposed, then the p-discriminant is a solution of (7), and (6) is a second approximation to a solution of (7). We must then have

$$4a_2k^2+(2b_1+c_0)k+d_0=0 \quad . \quad . \quad . \quad . \quad . \quad (11).$$

In other words, k is a root of (10). Hence one of the solutions furnished by (10) is the p-discriminant itself. The other, provided it be distinct, is a primitive touching the p-discriminant.

The condition (11) may be written (since $4a_2 \pm 0$,)

$$k^2+\frac{b_1}{2a_2}k+\frac{c_0}{4a_2}k+\frac{d_0}{4a_2}=0.$$

Now

$$c_0k+d_0=\frac{b_1^2-4a_2d_0}{4a_2}+d_0;$$

$$=\frac{b_1^2}{4a_2}$$

Hence (11) may be written

$$(k+b_1/4a_2)^2=0,$$

that is to say,

$$b_1^2-4a_2d_0+b_1c_0=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

This last condition reduces k to

$$k=-b_1/4a_2;$$

hence the other root of (10) is

$$\lambda=-d_0/b.$$

The approximations to the p-discriminant and the primitive, therefore, are

$$p\text{-discriminant, } y=-\frac{b_1}{4a_2}x^2 \quad . \quad . \quad . \quad . \quad . \quad (13);$$

$$\text{Primitive,} \qquad y=-\frac{d_0}{b_1}x^2 \quad . \quad . \quad . \quad . \quad . \quad (14),$$

which are in general distinct. Hence, *if any branch of the* p-*discriminant is a solution of the differential equation that branch is an envelope singular solution; that is to say, at every point there is a primitive distinct from the branch of the* p-*discriminant in question which touches that branch.*

We may note, in passing, that under the circumstances supposed the discriminant of the quadratic function

$$4a_2\lambda^2+(2b_1+c_0)\lambda+d_0$$

is a perfect square (since the roots are $-b_1/4a_2$ and $-d_0/b_1$). In fact, we have

$$\begin{aligned}(2b_1+c_0)^2-16a_2d_0&\\ &=4(b_1^2-4a_2d_0)+4b_1c_0+c_0^2\\ &=c_0^2,\end{aligned}$$

by virtue of (12).

To find the Conditions in the most General Case that the p-*discriminant furnish a tac-locus.*

The necessary conditions will be best seen by using NEWTON'S diagram to estimate the relative orders of the terms in the differential equation. If we assume, as will be justified by the result, that it is unnecessary to go beyond the term in p^2, we may write our equation (with the same origin and axes as heretofore)

$$b_0x+c_0y+d_0x^2+e_0xy+f_0y^2+(b_1x+c_1y)p+a_2p^2=0 \quad . \quad . \quad . \quad (15).$$

If we remember that p is of the same order as y/x, we may, for the mere purpose of estimating the order of the terms, write the equation in the form

$$x^2(b_0x+c_0y+d_0x^2+e_0xy+f_0y^2)+xy(b_1x+c_1y)+a_2y^2=0 \quad . \quad . \quad (16).$$

Arranging the terms in NEWTON'S diagram, we have figure 2. If two integral curves touch each other at the origin, we must have two approximations of the form $y=\lambda x^a$; and there must be a group of at least three effective terms: that is, there must be three outlying points in the diagram in a straight line next the origin. As a first condition, therefore, the term in x^3 must disappear, *i.e.*, $b_0=0$. If this condition alone were satisfied, we should fall back on the case last discussed. In order that the p-discriminant may not touch the two integral curves that have a common value of p at the origin, it is further necessary that $c_0=0$. If we retain only the three effective terms, the differential equation may be written

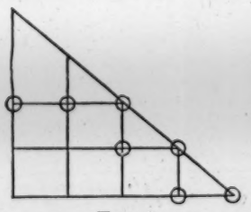

FIG. 2.

$$d_0x^2+b_1xp+a_2p^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17).$$

If now we put $y=\lambda x^a$, we see that $a=2$, and

$$d_0+2b_1\lambda+4a_2\lambda^2=0.$$

There are therefore two first approximations, viz. :—

$$2a_2y=\{-b_1\pm\sqrt{(b_1^2-4a_2d_0)}\}x^2 \quad . \quad . \quad . \quad . \quad . \quad (18),$$

which correspond to two integral curves which touch at the origin.

It remains to consider the nature of the p-discriminant near the origin. For this purpose it is necessary to retain more terms in the differential equation, for y and x are now of the same order of magnitude. Since p is small, the following equations will be sufficient for our purpose :—

$$\left.\begin{aligned} d_0x^2+e_0xy+f_0y^2+(b_1x+c_1y)p+a_2p^2=0,\\ b_1x+c_1y+2a_2p=0. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (19).$$

Eliminating p, we have for a first approximation to the p-discriminant

$$4a_2(d_0x^2+e_0xy+f_0y^2)-(b_1x+c_1y)^2=0 \quad . \quad . \quad . \quad . \quad (20).$$

This indicates that the p-discriminant has a double point at the origin. Hence, *the conditions that two integral curves touch each other and do not touch the* p*-discriminant at any particular point are* $b_0=0$, $c_0=0$; *and at such a point the* p*-discriminant has a double point.*

In order that the p-discriminant, or a branch of it, may be a tac-locus, the conditions $b_0=0$, $c_0=0$, must be satisfied at every point in question. Since it is impossible that every point of a continuous irreducible curve can be double, it follows that the p-discriminant must be reducible, must in fact contain a squared factor whose square root is the characteristic function of the tac-locus.

Hence, when the p*-discriminant furnishes a tac-locus, the two conditions* $b_0=0$ *and* $c_0=0$ *must be satisfied at every point of it. Its characteristic then contains a squared factor whose square root is the characteristic of the tac-locus.*

General expressions for the conditions for the existence of an envelope singular solution or a tac-locus can readily be obtained by transforming the differential equation

$$\phi(\mathrm{X},\mathrm{Y},\mathrm{P})\equiv \mathrm{A}_0+\mathrm{A}_1\mathrm{P}+\ldots\ldots+\mathrm{A}_n\mathrm{P}^n=0,$$

where the co-ordinates are (X, Y), and $\mathrm{P}=d\mathrm{Y}/d\mathrm{X}$, to the tangent and normal at the point (x, y) as axes. If the new co-ordinates be (ξ, η), $\varpi=d\eta/d\xi$, and $\lambda=1/\sqrt{(1+p^2)}$, $\mu=p/\sqrt{(1+p^2)}$, we have $\mathrm{X}=x+\lambda\xi-\mu\eta$, $\mathrm{Y}=y+\mu\xi+\lambda\eta$, and $\mathrm{P}=(p+\varpi)/(1-p\varpi)=$ $p+(1+p^2)\varpi+p(1+p^2)\varpi^2+\ldots=p+\underline{a\varpi+\beta\varpi^2}+\ldots$, say.

The differential equation then becomes

$$\phi(x+\lambda\xi-\mu\eta,\ y+\mu\xi+\lambda\eta,\ p+a\varpi+\beta\varpi^2+\ldots\ldots)=0 \quad . \quad . \quad (21).$$

This gives to a sufficient approximation for our present purpose

$$\begin{aligned} &\phi+\phi_x(\lambda\xi-\mu\eta)+\phi_y(\mu\xi+\lambda\eta)+\phi_p(a\varpi+\beta\varpi^2)\\ &+\tfrac{1}{2}[\phi_{xx}(\lambda\xi-\mu\eta)^2+\phi_{yy}(\mu\xi+\lambda\eta)^2+\phi_{pp}a^2\varpi^2\\ &+2\phi_{xy}(\lambda\xi-\mu\eta)(\mu\xi+\lambda\eta)+2\phi_{px}(\lambda\xi-\mu\eta)(a\varpi+\beta\varpi^2)\\ &\qquad+2\phi_{py}(\mu\xi+\lambda\eta)(a\varpi+\beta\varpi^2)]=0 \quad . \quad . \quad (22). \end{aligned}$$

If we use our original notation for the coefficients, and remember that, since (x, y) is supposed to be a point on the p-discriminant, we have $\phi=0$, $\phi_p=0$, we get

$$\begin{aligned} a_0&=\phi=0, & d_0&=\tfrac{1}{2}(\lambda^2\phi_{xx}+2\lambda\mu\phi_{xy}+\mu^2\phi_{yy}),\\ b_0&=\lambda\phi_x+\mu\phi_y, & e_0&=\lambda^2\phi_{xy}+\lambda\mu(\phi_{yy}-\phi_{xx})-\mu^2\phi_{xy},\\ c_0&=-\mu\phi_x+\lambda\phi_y, & f_0&=\tfrac{1}{2}(\lambda^2\phi_{yy}-2\lambda\mu\phi_{xy}+\mu^2\phi_{xx}),\\ a_1&=\alpha\phi_p=0, & a_2&=\tfrac{1}{2}(\beta\phi_p+\alpha^2\phi_{pp})=\tfrac{1}{2}\alpha^2\phi_{pp} \quad . \quad (23).\\ b_1&=\alpha(\lambda\phi_{px}+\mu\phi_{py}),\\ c_1&=\alpha(-\mu\phi_{px}+\lambda\phi_{py}), \end{aligned}$$

The general form of the condition $b_0=0$ is, therefore, $\lambda\phi_x+\mu\phi_y=0$, *i.e.*, $\phi_x+p\phi_y=0$. *Hence the necessary and sufficient condition in the most general case that the* p*-discriminant furnish an envelope singular solution is that the three equations in* x, y, p

$$\phi=0, \quad \phi_p=0, \quad \phi_x+p\phi_y{}^*=0 \quad . \quad . \quad . \quad . \quad . \quad (24)$$

have a onefold infinity of common solutions. These common solutions furnish the envelope.

If, as will in general happen, the three equations have only a finite number of solutions in common, then the corresponding points will be tac-points at which the two touching branches touch the p*-discriminant locus.*

Since $b_0=0$, $c_0=0$ are equivalent to $(\lambda^2+\mu^2)\phi_x=0$, $(\lambda^2+\mu^2)\phi_y=0$, that is, to $\phi_x=0$, $\phi_y=0$, it follows that, *in the most general case, the* p*-discriminant furnishes a tac-locus when the four equations in* x, y, p

$$\phi=0, \quad \phi_p=0, \quad \phi_x=0, \quad \phi_y=0 \quad . \quad . \quad . \quad . \quad . \quad (25)$$

have a onefold infinity of common solutions, the corresponding points being the tac-locus.

If, as may happen in special cases, the four equations have a finite number of common solutions, the corresponding points are tac-points, at which the touching integral branches do not in general touch the p*-discriminant, but at which the* p*-discriminant itself has double points.*

* It is easy to see in another way that $\phi_x+p\phi_y=0$ is simply the condition that the p-discriminant is an integral of the equation: for at any point of the p-discriminant $dx:dy$ is given by

$$\phi_x dx+\phi_y dy+\phi_p dp=0$$
$$\phi_{px}dx+\phi_{py}dy+\phi_{pp}dp=0.$$

Since $\phi_p=0$, the first of these equations gives

$$\phi_x+\phi_y dy/dx=0.$$

The condition that the p-discriminant be a solution is $p=dy/dx$; hence,

$$\phi_x+p\phi_y=0.$$

In deducing the above conditions it has been tacitly supposed that p is not infinite. This special case may be treated by change of axes, by special investigation, or by the method of limits.

We have seen that the tac-locus, if it exists, is furnished by a squared factor in the p-discriminant. The first approximation,

$$4a_2(d_0x^2+c_0xy+f_0y^2)-(b_1x+e_1y)^2=0\,,$$

must therefore give a pair of coincident straight lines. The condition for this is

$$4a_2d_0f_0+e_0b_1c_1-a_2e_0^2-d_0c_1^2-f_0b_1^2=0\,.*$$

This last equation ought, therefore, to be a derivative of $b_0=0$, $c_0=0$ when these are satisfied at every point of a branch of the p-discriminant. It will be an interesting test of the accuracy of the foregoing theory to verify that this is actually the case. If we substitute the values of a_2, &c., calculated above, we find

$$\begin{aligned}&4a_2d_0f_0+e_0b_1c_1-a_2e_0^2-d_0c_1^2-f_0b_1^2\\&\equiv\tfrac{1}{2}\alpha^2(\lambda^2+\mu^2)^2\{\phi_{pp}(\phi_{xx}\phi_{yy}-\phi^2_{xy})-\phi_{xx}\phi^2_{py}+2\phi_{xy}\phi_{px}\phi_{py}-\phi_{yy}\phi^2_{px}\}\,,\\&\equiv\tfrac{1}{2}(1+p^2)^2\{\phi_{pp}(\phi_{xx}\phi_{yy}-\phi^2_{xy})-\phi_{xx}\phi^2_{py}+2\phi_{xy}\phi_{px}\phi_{py}-\phi_{yy}\phi^2_{px}\}\,.\end{aligned}$$

Now, from the equations $\phi_p=0$, $\phi_x=0$, $\phi_y=0$, which are supposed to be satisfied at every point of the branch of the p-discriminant in question, we have

$$\begin{aligned}\phi_{px}dx+\phi_{py}dy+\phi_{pp}dp&=0\,,\\\phi_{xx}dx+\phi_{xy}dy+\phi_{px}dp&=0\,,\\\phi_{xy}dx+\phi_{yy}dy+\phi_{py}dp&=0\,;\end{aligned}$$

whence, eliminating $dx:dy:dp$, we find

$$\phi_{pp}(\phi_{xx}\phi_{yy}-\phi^2_{xy})-\phi_{xx}\phi^2_{py}+2\phi_{xy}\phi_{px}\phi_{py}-\phi_{yy}\phi^2_{px}=0\,,$$

which establishes the derivation.

Geometrical Interpretation of the Conditions for a tac-locus.

If we regard (x, y, p) as the co-ordinates of a point in space of three dimensions, then the equation $\phi(x, y, p)=0$ may be taken as representing a surface. *The conditions for a tac-point or a tac-locus are therefore simply that the surface $\phi=0$ have a conical point or a double line.*

Looking at the matter from this point of view, or considering the symmetry of the conditions as regards (x, y, p), we see at once that *if the differential equation*

* It may be of interest to note that this is the condition that the function

$$a_2p^2+(b_1x+c_1y)p+d_0x^2+e_0xy+f_0y^2,$$

obtained by retaining only such terms of the characteristic of the differential equation as are required to determine an accurate first approximation to the p-discriminant, is decomposable into factors which are integral and linear in x, y, p.

$$\phi(x, y, p)=0$$

have a tac-locus, then the five equations, $\phi(x, p, y)=0$, $\phi(y, x, p)=0$, $\phi(y, p, x)=0$, $\phi(p, y, x)=0$, $\phi(p, x, y)=0$, *have each in general a tac-locus also.*

We say, *in general*, because it may happen that there is not in each case a onefold infinity of values of x and y, and then we have merely a tac-point. Thus, for example, let us take GLAISHER's Example VIII. (*Math. Mess.*, xii. p. 6)

$$\phi\equiv(x^2-a^2)p^2-2xyp-x^2=0.$$

The conditions for a tac-locus are $(x^2-a^2)p^2-2xyp-x^2=0$, $2xp^2-2yp=0$, $-2xp=0$, $2(x^2-a^2)p-2xy=0$. These are satisfied by $x=0$, $y=y$, $p=0$: so that $x=0$ is a tac-locus. If we interchange x and y, we get the equation

$$(y^2-a^2)p^2-2xyp-y^2=0.$$

To get the tac-conditions for this new equation we have to adjoin the equations $x=x$, $y=0$, $p=0$: $y=0$ is, therefore, a tac-locus. If, however, we interchange p and y, we get

$$(x^2-a^2)y^2-2xyp-x^2=0,$$

the additional tac-conditions for which are $x=0$, $y=0$, $p=p$. Here, therefore, there is merely a tac-point.

Since a surface of the second degree cannot have a double line without degenerating, it follows that *an irreducible differential equation of the first order which is integral in* x, y, p, *and whose degree in* (x, y, p) *collectively does not exceed the second, can have no tac-locus*, a result which might also have been deduced from the remark made above, p. 810.

Locus of the Points of Inflexion on the Integral Curves of the Differential Equation—

$$A_0+A_1p+\ldots.+A_np^n=0.$$

If, instead of considering the integral curve as a locus of points, we consider it as the envelope of its tangents, we see that to a locus of cusps on the integral curves corresponds a locus of inflexions. As the cusp-locus is present in the general case, the inflexion-locus will also be present in the general case.

The conditions for an inflexion on one of the integral curves at any point can readily be found by the methods above used. Let us take, as before, the point in question for origin and the tangent to the integral in question as axis of x; then, remembering that y is of higher order than x, and omitting terms that are *prima facie* negligible, we may write the differential equation in the form

$$(b_0x+c_0y+d_0x^2)+a_1p=0\,, \qquad . \quad . \quad . \quad . \quad . \quad (26),$$

where $a_1 \neq 0$, since only one value of $p=0$ when $x=0$, $y=0$.

For the purpose of estimating the order of the terms we may write our equation in the form

$$x(b_0x+c_0y+d_0x^2)+a_1y=0 \qquad . \quad . \quad . \quad . \quad . \quad (27),$$

the NEWTON'S diagram for which is given by the annexed figure (3). Hence, if $b_0 \neq 0$, the approximation to the integral curve is given by $b_0x+a_1p=0$, which gives $2a_1y+b_0x^2=0$, corresponding to an ordinary point. As a necessary condition, we must therefore have $b_0=0$; and this is, in general, sufficient; for the first approximation is now given by $d_0x^2+a_1p=0$, which gives $3a_1y+d_0x^3=0$, corresponding to an inflexion. If we translate this result into general symbols, we have as the condition for an inflexion at (x, y), on the branch corresponding to the value p, $\phi_x+p\phi_y=0$. *Hence the locus of points which are inflexions on integral curves is given by*

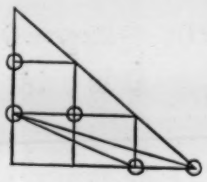

FIG. 3.

$$\phi=0,\ \phi_x+p\phi_y=0 \qquad . \quad . \quad . \quad . \quad . \quad . \quad (28),$$

where p *is to be treated as an arbitrary parameter, viz., it is the tangent of the inclination to the* x*-axis of that branch of the integral curve which has an inflexion at* (x, y).

Comparing the conditions for an envelope singular solution with the result now obtained we see that they may be expressed as follows:—*In order that there may be an envelope singular solution it is necessary and in general sufficient that the cusp-locus and the inflexion-locus have a branch in common.*

Since the differential equation to the orthogonal trajectories of the family represented by

$$\phi(x,y,p)=0\,,$$

is

$$\phi(x,y,-1/\varpi)=0\,,$$

the *inflexion-locus for the orthogonal trajectories is given by*

$$\left.\begin{aligned}&\phi(x,y,-1/\varpi)=0\,,\\&\phi_x(x,y,-1/\varpi)+\varpi\phi_y(x,y,-1/\varpi)=0\end{aligned}\right\};$$

or, putting $p=-1/\varpi$, by

$$\phi(x,y,p)=0, p\phi_x(x,y,p)-\phi_y(x,y,p)=0\,.$$

Since, in general, $\phi_x+p\phi_y=0$, $p\phi_x-\phi_y=0$ are equivalent to $\phi_x=0$, $\phi_y=0$, and since the p-discriminant locus is obviously the same for the original family and for the orthogonal trajectories, it follows that *at a tac-point where the tangent does not touch the* p*-discriminant locus this locus must have a point in common with the inflexion-loci of*

the original family and of the orthogonal trajectories. The condition for the existence of a tac-locus where there is no contact with the p*-discriminant locus is that the* p*-discriminant locus, the locus of inflexions, and the locus of inflexions on the orthogonal trajectories must have a branch in common.**

Discussion of the Equation

$$c_0y+d_0x^2+b_1xp+a_2p^2=0.$$

Since this equation gives the first approximation in the general case to the form of an integral curve in the neighbourhood of an envelope, it is a matter of some interest to investigate the general nature of its integral.

Since $a_2\neq 0$, we may put $a_2=1$. Dropping the suffixes we may write

$$ay+bx^2+cxp+p^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (29).$$

When the Equation (15) *has an Envelope Singular Solution its Integral is a Family of Algebraic Curves* (*Parabolæ*).

If we put $\xi=x^2$, $\varpi=dy/d\xi$, (29) becomes

$$ay+(b+2c\varpi+4\varpi^2)\xi=0.$$

If we solve for ϖ and put $y=v\xi$, we get

$$v+\xi\frac{dv}{d\xi}=\frac{-c\pm\sqrt{(c^2-4b-4av)}}{4};$$

whence

$$\frac{4adv}{c+4v\pm\sqrt{(c^2-4b-4av)}}+\frac{d\xi}{\xi}=0.$$

Let $u=\pm\sqrt{(c-4b-4av)}$: then we have

$$\frac{-2udu}{ac+c^2-4b-u^2-au}+\frac{d\xi}{\xi}=0.$$

* The general existence of the cusp-locus of the integral family of a differential equation of the first order was indicated as early as 1851 by De Morgan (*Camb. Phil. Trans.*, vol. ix. pt. 2, p. 113). The earliest absolutely explicit statement of the theorem seems to have been made by Darboux (*Comptes Rendus*, t. lxx. p. 1331; also t. lxxi. p. 267, 1870). In an extremely interesting paper in the *Bulletin des Sciences Mathematiques*, &c., t. iv., 1873, p. 158, Darboux establishes most of the propositions above given. It is surprising that Darboux's work does not seem to have attracted the notice of Cayley. Reference may also be made to Clebsch, *Mathematische Annalen*, Bd. vi. p. 211, 1873; and to Clebsch's theory of "Connexes," *Vorlesungen uber Geometrie*, Bd. i. p. 1014 *et seqq.* We have thought it worth while to deduce these results throughout by the approximative method first employed by Briot and Bouquet, because this method is a general one, applicable to the discrimination of special cases, such as arise when an envelope is also a cusp-locus or a tac-locus, &c.; and because this method is little used by English mathematicians.

Now, by (12), since (15) has a singular solution we must have

$$ac+c^2-4b=0.$$

Hence

$$\frac{2du}{u\pm a}+\frac{d\xi}{\xi}=0.$$

The integral is therefore

$$(u\pm a)^2\xi=\mathrm{A},$$

or

$$ax\pm\sqrt{(-acx^2-4ay)}=\mathrm{B},$$

the rational form of which is

$$(ax-\mathrm{B})^2+a(4y+cx^2)=0 \quad . \quad . \quad . \quad . \quad . \quad (30),$$

representing a family of parabolæ the envelope of which is obviously the parabola

$$4y+cx^2=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad (31).$$

To find the Condition that the Equation (15) *may have an Algebraic Integral*

$$(a\neq 0,\quad b\neq 0,\quad c\neq 0).$$

Proceeding as before, we reduce the equation to the form

$$\frac{2udu}{u^2+au-f}+\frac{d\xi}{\xi}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (32),$$

where

$$f=c^2+ac-4b \quad . \quad . \quad . \quad . \quad . \quad . \quad (33).$$

Let

$$u^2+au-f\equiv(u-\lambda)(u-\mu).$$

Then

$$\frac{2u}{u^2+au-f}=\frac{2}{\lambda-\mu}\left(\frac{\lambda}{u-\lambda}-\frac{\mu}{u-\mu}\right);$$

and the integral of (6) is

$$\frac{2\lambda}{\lambda-\mu}\log(u-\lambda)-\frac{2u}{\lambda-\mu}\log(u-\mu)+\log\xi=\mathrm{C} \quad . \quad . \quad . \quad (34).$$

If

$$\begin{aligned}\beta&=a^2+4f=a^2+4c^2+4ac-16b,\\&=(a+2c)^2-16b, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35),\end{aligned}$$

then

$$2\lambda=-a+\sqrt{\beta},\quad 2\mu=-a-\sqrt{\beta};$$

and we get for the primitive

$$\left(\frac{-a}{\sqrt{\beta}}+1\right)\log(u-\lambda)-\left(\frac{-a}{\sqrt{\beta}}-1\right)\log(u-\mu)+\log\xi=\mathrm{C};$$

or

$$\left(\frac{u-\mu}{u-\lambda}\right)^{\frac{\alpha}{\sqrt{\beta}}}(u-\lambda)(u-\mu)\xi=A \quad . \quad . \quad . \quad . \quad . \quad (36),$$

where

$$u=\mp\sqrt{\{c^2-4b-4ay/x^2\}}.$$

Since $\alpha\neq 0$, it is obvious that the necessary and sufficient condition that (36) be algebraic is that β be a perfect square, that is, that $(a+2c)^2-16b$ be a perfect square. It is assumed, of course, that a, b, c are commensurable.

The condition that (29) may have a singular solution is

$$c^2+ac-4b=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (37).$$

This is not in general satisfied when the primitive is algebraic; although the primitive is always algebraic when (37) is satisfied; viz., in this case, $(a+2c)^2-16b$ reduces to $(a+2c)^2-4c^2-4ac=a^2$.

As this contradicts a well-known result of CAYLEY'S, it may be well to examine a simple particular case of a differential equation which has an algebraic primitive, but has no singular solution. By means of the above results we can construct an infinity of such cases; the fact being that it is the exception and not the rule that there is a singular solution when the primitive is algebraic.

Example of a Differential Equation which has an Algebraic Primitive but has no Singular Solution.

Consider

$$3y+\tfrac{1}{5}x^2-\tfrac{2}{3}xp+p^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

the p-discriminant of which is

$$y=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

and gives no solution of (1).

We may write (1) in the form

$$p=\tfrac{1}{3}x\pm\sqrt{(-3y)},$$

or, if $x^2=\xi$,

$$2\frac{dy}{d\xi}=\tfrac{1}{3}\pm\sqrt{\left(-\frac{3y}{\xi}\right)}.$$

Put $y=v\xi$, and we get

$$2\xi\frac{dv}{d\xi}+2v=\tfrac{1}{3}\pm\sqrt{(-3v)},$$

which may be written

$$\frac{4dv}{4v-\frac{2}{3}\mp\sqrt{(-12v)}}+\frac{d\xi}{\xi}=0 \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Let

$$u=\mp\sqrt{(-12v)},$$
$$u^2=-12v;$$

whence

$$\frac{2udu}{u^2+2-3u}+\frac{d\xi}{\xi}=0;$$

that is,

$$\left(\frac{4}{u-2}-\frac{2}{u-1}\right)du+\frac{d\xi}{\xi}=0 \quad . \quad . \quad . \quad . \quad . \quad (4).$$

The integral of (4) is

$$(u-2)^2\sqrt{\xi}/(u-1)=-4c \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Now (5) may be written

$$(u^2-4u+4)x+4cu-4c=0,$$

or

$$xu^2-4(x-c)u+4(x-c)=0.$$

Hence

$$u=2\frac{(x-c)\pm\sqrt{\{c(c-x)\}}}{x};$$

whence, squaring and substituting the value of u, we get

$$3y=-(x-c)(x-2c)\pm 2c^{\frac{1}{2}}(c-x)^{\frac{3}{2}} \quad . \quad . \quad . \quad . \quad . \quad (6);$$

or, in rational form,

$$(x^2+12y)c^2-2x(x^2+9y)c+(x^2+3y)^2=0 \quad . \quad . \quad . \quad . \quad (7).$$

The c-discriminant is therefore

$$x^2(x^2+9y)^2-(x^2+12y)(x^2+3y)^2=0,$$

which reduces to

$$y^3=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

The primitive curve can be readily traced from (6).

We observe, in the first place, that the value of y is unchanged if we change the signs of both c and x. It follows that the curve of the family for any negative value of c is the image in the y-axis of the curve for the corresponding positive value of c. We may therefore confine our attention to positive values of c; and we also see that, for real values of y, x must not exceed $+c$.

Since $2c-x \nless 2\sqrt{\{c(c-x)\}}$, the value of y is negative for all admissible values of x, and vanishes only when $x=0$ and $x=c$.

From (6) we have

$$y'=\tfrac{1}{3}(3c-2x)\mp\sqrt{\{c(c-x)\}} \quad . \quad . \quad . \quad . \quad . \quad (9);$$

$$y''=-\tfrac{2}{3}\pm\tfrac{1}{2}\sqrt{\{c/(c-x)\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10).$$

If we speak of the parts of the curve corresponding to the upper and lower signs as the first and second branches, we see at once that for the second branch y' is always positive and y'' always negative. This branch crosses the y-axis at $(0, -\frac{4}{3}c^2)$ and is uniformly convex to the x-axis.

For the first branch y' vanishes when $x=0$ and when $x=\frac{3}{4}c$; these give a maximum turning-point at the origin and a minimum turning-point at $(\frac{3}{4}c, -\frac{7}{24}c^2)$.

At $x=c$ there is obviously a cusp, the value of y' being $\frac{1}{3}c$.

Near the origin, approximation to the first branch is given by

$$y=-\tfrac{1}{12}x^2+\tfrac{1}{24}\frac{x^3}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11);$$

from which we see that all the first branches osculate the parabola $12y+x^2=0$ at the origin; and depart less and less from it the more we increase c.

It is also obvious from (7) that this parabola

$$12y+x^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

is the limiting form of the integral curve corresponding to $c=\infty$; and also that it divides the region below the x-axis into two districts, in the upper of which the two values of c corresponding to the two curves of the family which pass through a given point are of the same sign in the lower of which of opposite signs.

The following figure, therefore, gives a sufficient representation of the forms of the curves of the family for positive values of c. For negative values we have simply to reflect the diagram in the y-axis. KOAB, figure (4), is the curve corresponding to any

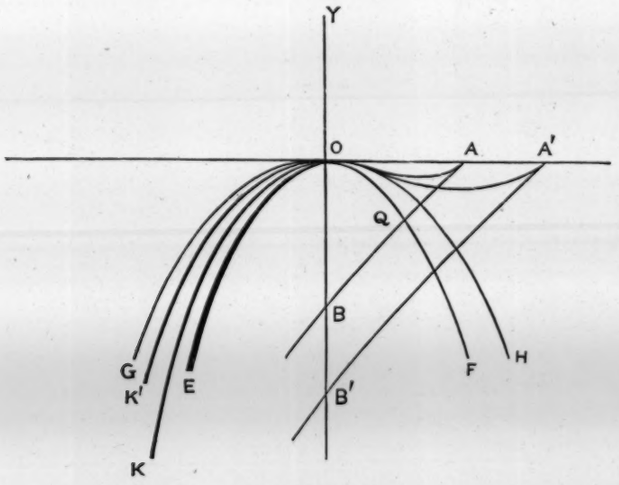

FIG. 4.

finite value of c, K'OA'B' that corresponding to a greater value. The parabola GOH is the limiting form corresponding to $c=\infty$, the second branch of which is altogether at ∞. The limiting form corresponding to $c=+0$ is the left-hand part of the parabola EOF, whose equation, as is easily seen from (7), is

$$3y+x^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (13).$$

We have thickened this part to indicate that it must be reckoned twice; for, as A

moves towards O, it is obvious that OK approaches OE from one side and AB approaches the same limit from the other.

It must be carefully noticed that the other half, OF, of the parabola (12) is the limiting form for negative values of c. If this be forgotten, confusion will arise regarding the two branches of the primitive family which pass through any point of the plane.

Thus, for example, the two curves through P are a first branch of one primitive and a second of another, both corresponding to positive values of c. At any point Q below EOF the two curves are both second branches—one corresponding to a positive, the other to a negative value of c: in particular, at a point Q on the dotted branch of (13) the two curves are BQA and OQF.

At the origin all the primitive curves have the same first approximation, viz., the parabola (12). The second approximations for any two curves c and c' are, as we have seen,

$$\left.\begin{aligned} x^2+12y-\tfrac{1}{2}x^3/c=0 \\ x^2+12y-\tfrac{1}{2}x^3/c'=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (14).$$

Quà intersections at the origin this pair of equations is equivalent to $x^2+12y=0$ and $x^3=0$, that is to $x=0$, $y=0$ thrice. Hence every integral curve is intersected by its consecutive in three points at (0, 0).

It is readily found from NEWTON'S diagram that all the integral curves have at ∞ the common first approximation

$$(x^2+3y)^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (15);$$

and that the second approximation to any curve c is

$$(x^2+3y)^2+4cx^3=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16).$$

If we apply to (16) the linear transformation $x=\xi/\eta$, $y=1/\eta$, we get

$$(\xi^2+3\eta)^2+4c\xi^3\eta=0,$$

or, to the same approximation as before,

$$(\xi^2+3\eta)^2-\tfrac{4}{3}c\xi^5=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17).$$

To the multiple point (0, ∞) on (16) corresponds the multiple point (0, 0) of the same order and species on (17).

Now (17) has a node-cusp at (0, 0), for which $\delta=1$, $\kappa=1$ (see SALMON'S *Higher Plane Curves*, § 243).

If we combine with (17) another equation

$$(\xi^2+3\eta)^2-\tfrac{4}{3}c'\xi^5=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (18),$$

and confine ourselves to intersections at the origin, we shall find the multiplicity of the intersection of any integral curve with another consecutive or non-consecutive at (0, ∞).

Now (17) and (18) are equivalent to $(\xi^2+3\eta)^2-\frac{4}{3}c\xi^5=0$, $\xi^5=0$; that is to $(\xi^2+3\eta)^2=0$, $\xi^5=0$; that is to $\eta^2=0$, $\xi^5=0$. Hence ten intersections of (17) and (18) are condensed at $(0, 0)$; and therefore any two consecutive (or non-consecutive) integral curves intersect ten times at $(0, \infty)$ . . .

These results may be verified by finding the x-eliminant of (7) and the equation derived by differentiating its characteristic with respect to c, viz.,

$$(x^2+12y)c-x(x^2+9y)=0 \quad . \quad . \quad . \quad . \quad . \quad (19).$$

The result is

$$x^3(x-c)^3=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

Since the degree of (20) ought to be 16, we see that two consecutive integral curves intersect in 3 points at $(0, 0)$, 3 at $(c, 0)$, and 10 at $(0, \infty)$.

The family of integral curves has therefore no envelope, real or imaginary; but merely the cusp-locus $y=0$ and the fixed tac-points $(0, 0)$, $(0, \infty)$.

It appears, therefore, that the p-discriminant curve in the present case, notwithstanding that the primitive is algebraic, is, as usual, a cusp-locus, and is in no proper sense an envelope. It might, perhaps, be contended that it is an envelope in the sense that every primitive touches every other at one particular point, viz., $(0, 0)$, or $y=0$; but, on the other hand, $y=0$, $p=0$ does not satisfy the differential equation, and is therefore not a solution at all, much less a singular solution.

Moreover, it is clear from all that precedes that, although it is true that when the differential equation

$$ay+bx^2+cxp+p^2=0$$

has a singular solution, its primitive is algebraic; yet, on the other hand, it is the exception, and not the rule, that it has a singular solution when its primitive is algebraic.

I have gone carefully into this matter, because the conclusion just arrived at shows that a proposition laid down by CAYLEY in connection with his well known Geometrical Theory of Singular Solutions of Differential Equations of the first order is erroneous, or at least very misleading. In his second paper on the subject (*Mess. Math.*, vol. vi. p. 23, 1877) the following passage occurs:—"Consider now a system of algebraic curves $U=0$, where U is, as regards (x, y), a rational integral function of the order m, and depends in any manner on an arbitrary parameter C, *I say that there is always a proper envelope*, which envelope is the singular solution of the differential equation obtained by the elimination of C from the equation $U=0$ and the derived equation in regard to (x, y). *It follows that the differential equation* $(L, M, N \not\!\!\!

$U=0$ of order m, having singularities equivalent to δ double points and κ cusps. Of the intersections of $U=0$, with its consecutive $U+\delta_c U=0$, two will coincide with each double point and three with each cusp, leaving $m^2-2\delta-3\kappa$ other points of intersection. If n be the class of the curve $m^2-2\delta-3\kappa=m+n$, a number which cannot vanish; hence there is always an envelope, viz., the locus of these, $m^2-2\delta-3\kappa$ points.

The fallacy in this reasoning consists in assuming that the $m^2-2\delta-3\kappa$ points are necessarily spread out into a locus. It is, in fact, an inference that may be drawn from the above investigation that, *in general*, when a differential equation of the first order has an algebraic integral, this is not the case. So that only particular kinds of algebraic families can be integrals of equations of this description.

If we examine the particular case above discussed, for which $m=4$, $\delta=1$, $\kappa=2$* we see that $m^2-2\delta-3\kappa=8$. The eight points which ought, according to CAYLEY's theory, to form the envelope are concentrated, three at (0, 0) and the remaining five at $(0, \infty)$.

It is somewhat surprising that GLAISHER (*Mess. Math.*, xii. p. 2, 1883) seems to endorse the statement of CAYLEY just referred to, seeing that GLAISHER's examples (iii), (xiii), (xiv), (xv), (xx)† are instances to the contrary. It might be inferred from the somewhat guarded language used by FORSYTH (*Differential Equations*, § 30), and from his reference to CAYLEY, that he attaches some value to CAYLEY'S result; but he has been kind enough to inform me that he is not to be understood as endorsing the proposition in dispute.

Trinodal Quartic Family which has no Envelope.—Inasmuch as the quartic family already discussed presents a peculiarity in respect that there is a condensed singularity; it may be well in the interest of the theory of envelopes to show that the degeneration of the envelope is not due to this cause. This we shall do by constructing a trinodal quartic whose singularities are all distinct and which has no proper envelope. The possibility of this may be seen *à priori* by considering that we can construct a quartic which has cusps at two given points, B and C, and given cuspidal tangents at these points, which passes through a given point A, and has a given tangent at A: this involves $5+5+2=12$ conditions. That there be a third node (position not specified) involves one more condition, leaving still one degree of freedom; so that we have a *family* of quartics fulfilling the given conditions. Now (as may be seen by discussing the intersection at the origin of the curves $y^2=cx^3$, $y^2=c^1x^3$ ‡) any two (and therefore

* The curves are unicursal quartics: by considering the intersection with the parabola $3y=\mu x(x-c)$ we find

$$x=4\mu c/(1+\mu)^2$$
$$3y=-4\mu^2(1-\mu)^2c^2(1+\mu)^4.$$

† There is an oversight in the interpretation of No. (xx).

‡ The two equations are equivalent to

$$y^2=cx^3,$$
$$(c-c^1)x^3=0;$$

that is to

$$x^3=0,$$
$$y^2=0,$$

which gave $x=0$, $y=0$ six times.

any consecutive two) curves of this family intersect each other six times at B, six times at C, and twice at A. The remaining two points of intersection for two consecutive curves are infinitely near the double point. Hence the family has no proper envelope; but merely (so far as movable intersections are concerned) a node locus which counts twice.

Moreover, the quartic does not degenerate, as we shall show by working out its equation *in the special case where the point* A *is the intersection of the cuspidal tangent at* B *and* C.

Let us use triple coordinates and take A, B, C for triangle of reference: and let us write the equation to the quartic

$$a_0z^4+(ax+by)z^3+(cx^2+dxy+ey^2)z^2+(fx^3+gx^2y+hxy^2+ky^3)z+u_4=0 \quad . \quad (1).$$

Since $z=0$, which joins the cusps, must give $x^2=0$ and $y^2=0$, we see at once that $u_4\equiv x^2y^2$ (dropping the useless constant). Also, since $x=0$ and $y=0$ are cuspidal tangents, $x=0$ must give $z^3=0$, and $y=0$ must give $z^3=0$; hence we must have $e=0$, $k=0$, $c=0$, $f=0$.

The condition that the curve pass through (0, 0, 1) is obviously $a_0=0$; and, if we take $x+y=0$ to be the fixed tangent at (0, 0, 1), it is easily seen that we must have $a=b$. Our equation now reduces to

$$f(x, y, z)\equiv a(x+y)z^3+dxyz^2+(gx^2y+hxy^2)z+x^2y^2=0 \quad . \quad . \quad . \quad (2).$$

We have

$$\begin{aligned}
f_x &\equiv az^3+dyz^2+(2gxy+hy^2)z+2xy^2;\\
f_y &\equiv az^3+dxz^2+(2hxy+gx^2)z+2x^2y;\\
f_z &\equiv 3a(x+y)z^2+\quad 2dxyz+(gx+hy)xy;\\
f_{xx} &\equiv 2gyz+2y^2;\\
f_{yy} &\equiv 2hxz+2x^2;\\
f_{zz} &\equiv 6a(x+y)z+2dxy;\\
f_{yz} &\equiv 3az^2+2dxz+2hxy+gx^2;\\
f_{zx} &\equiv 3az^2+2dyz+2gxy+hy^2;\\
f_{xy} &\equiv dz^2+2(gx+hy)z+4xy.
\end{aligned}$$

It will be seen that the conditions for double points at (0, 1, 0) and (1, 0, 0) are satisfied. In order that these points may be cusps, it is farther necessary that $\Sigma f_{xx}\xi^2+2\Sigma f_{yz}\eta\zeta$ shall be a complete square in ξ, η, ζ at the two points. Now this function reduces to $2\xi^2+2h\zeta\xi$ and $2\eta^2+2g\eta\zeta$ at (0, 1, 0) and (1, 0, 0) respectively; hence we must have $g=0$, $h=0$.

Our equation is now reduced to

$$a(x+y)z^3+dxyz^2+x^2y^2=0 \quad . \quad . \quad . \quad . \quad . \quad (3);$$

and it remains only to find the condition that the quartic have a third node. The conditions for a node are

$$az^3+dyz^2+2xy^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4),$$
$$az^3+dxz^2+2x^2y=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (5),$$
$$3a(x+y)z^2+2dxyz=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

Setting aside alternatives which lead to $z=0$, $x=0$ and $z=0$, $y=0$ (double points already existing), we find that (4) and (5) are equivalent to

$$az^3+dxz^2+2dx^3=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7),$$
$$x-y=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

The admissible solution or solutions of (7) and (8) must also satisfy (6). Hence, setting aside $x=0$, as before, we must have

$$3az+dx=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

Substituting the value of z/x given by (9) in (7) we get for the necessary and sufficient condition required

$$d^3+27a^2=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (10),$$

which will be satisfied if we take $a=c^3$, $d=-3c^2$. The coordinates of the third node are then $x=y=c$, $z=1$.

For these values

$$\Sigma f_{xx}\xi^2+2\Sigma f_{xy}\eta\xi$$

reduces to

$$2c^2\xi^2+2c^2\eta^2+6c^4\xi^2-6c^3\eta\xi-6c^3\xi\xi+2c^2\xi\eta \equiv 2c^2\{\xi-\omega\eta+(\omega-1)c\xi\}\{\xi-\omega^2\eta+(\omega^2-1)c\xi\},$$

where ω is an imaginary cube root of unity. *The node is, therefore, an acnode.*

The quartic family,

$$c^3(x+y)z^3-3c^2xyz^2+x^2y^2=0 \quad . \quad . \quad . \quad . \quad . \quad (11),$$

therefore, has fixed cusps at (1, 0, 0) *and* (0, 1, 0), *the cuspidal tangents being* $y=0$ *and* $x=0$, *a movable acnode* $x=y=c$, $z=1$; *each curve passes through the intersection of its cuspidal tangents and has a fixed tangent at that point.*

As a verification of the result already predicted, we may calculate the coordinates of the intersections of two consecutive curves of the family. These are given by

$$\left.\begin{aligned} c^3(x+y)z^3-3c^2xyz^2+x^2y^2=0,\\ c(x+y)z^3-2xyz^2=0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (12).$$

Now (12) is equivalent to the system

$$z^2=0, x^2y^2=0,$$

which gives (1, 0, 0) and (0, 1, 0) each four times, together with

$$\left.\begin{aligned} c^3(x+y)z^3 - 3c^2xyz^2 + x^2y^2 &= 0, \\ c(x+y)z - 2xy &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (13).$$

This last is equivalent to

$$\left.\begin{aligned} c^3(x+y)z^3 - 3c^2xyz^2 + \tfrac{1}{4}c^2(x+y)^2z^2 &= 0, \\ c(x+y)z - 2xy &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (14).$$

(14) is equivalent to $z^2=0$, $xy=0$, **which gives (1, 0, 0)** and 0, 1, 0) each twice, together with

$$\left.\begin{aligned} c(x+y)z - 3xy + \tfrac{1}{4}(x+y)^2 &= 0, \\ c(x+y)z - 2xy &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (15);$$

that is,

$$\left.\begin{aligned} (x-y)^2 &= 0, \\ c(x+y)z - 2xy &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (16);$$

that is,

$$\left.\begin{aligned} (x-y)^2 &= 0, \\ x(cz-x) &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (17).$$

Now (17) gives (0, 0, 1) and $(c, c, 1)$ **each twice. Hence** the intersections are (1, 0, 0) six times, (0, 1, 0) six times, **(0, 0, 1) twice, and $(c, c, 1)$** twice. There is, therefore, a node locus, but no envelope.

As a farther verification we may **calculate the c-discriminant** of (11). The result is

$$27z^6x^4y^4(x-y)^2 \quad . \quad . \quad . \quad . \quad . \quad (18).$$

The factor $(x-y)^2$ corresponds to the **node locus, the factors** x^4, y^4, z^6 to the sides of the triangle of reference, which are parts **of degenerate transition** quartics of the system.

By means of a conic passing **through A, B, C and** the acnode, it is easy to obtain rational expressions for the ratios of **the coordinates in** terms of a parameter θ. The result is

$$\left.\begin{aligned} x/y &= -2c\theta(\theta+c)/(\theta-c)^2, \\ y/z &= -2c\theta(\theta-c)/(\theta+c)^2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (19),$$

by means of which this interesting **family of curves may** readily be traced.

It would be easy to construct a **large number of examples** of the degeneration of the envelope of an algebraic family. It **will be sufficient to** add a pair of examples of cubics which have this property.

The cubic

$$z^3 + c^3xy(x+y) - 3c^2xyz = 0$$

has real inflexions at (0, 1, 0) *and* **(1, 0, 0),** ***the inflexional*** *tangents being* $x=0$, $y=0$ *respectively, passes through the fixed* ***point*** **(1, −1, 0)** ***and*** *has an acnode at* (1, 1, c).

Any two consecutive curves of **the family intersect** thrice at (0, 1, 0), thrice at

(1, 0, 0), once at (1, −1, 0), and twice at (1, 1, c). The family has no envelope; but merely the node locus $x-y=0$.

The c-discriminant locus is

$$27x^6x^2y^2(x-y)^2=0.$$

The cubic

$$9c^2x^2-4cx-(12y^3+12y^2+4y)=0,$$

or

$$x-\frac{2}{9c}\{1\pm(3y+1)^{\frac{3}{2}}\}$$

has a fixed inflexion and inflexional tangent at ∞ *and passes through the fixed points*

$$\text{A.}\quad (0,0),\qquad \text{B.}\quad \left(0,\frac{-3+i\sqrt{3}}{6}\right),\qquad \text{C.}\quad \left(0,\frac{-3-i\sqrt{3}}{6}\right).$$

It has a cusp at (2/9c, −1/3). *The intersections of two consecutive curves are* (∞, 0) *thrice*, A, B, C *and the cusp thrice. There is therefore merely a cusp locus* (fig. 4).

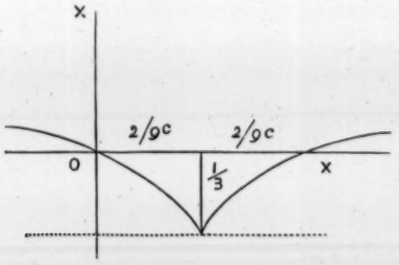

FIG. 5.

The c-discriminant locus is

$$16x^2(3y+1)^3=0.$$

$x^2=0$ corresponds to a degenerate curve of the family for which $c=\infty$.

The simplest case of all in which the envelope degenerates into a point-discrete is the linear pencil

$$cu+v=0,$$

where u and v are integral functions of x and y. In this case each curve intersects every other consecutive or non-consecutive in the points of intersection of $u=0$, $v=0$; and the corresponding differential equation of the first order and first degree has, as is well known, no envelope singular solution. The proper consideration of this case alone is sufficient to show that no theory of envelopes which takes no account of the manner in which the arbitrary constant is involved can be of much value for the theory of differential equations.

APPENDIX.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

CONTENTS.

THE COUNCIL OF THE SOCIETY, ... 829

ALPHABETICAL LIST OF THE ORDINARY FELLOWS, ... 831

LIST OF HONORARY FELLOWS, ... 847

LIST OF ORDINARY FELLOWS ELECTED DURING SESSION 1894–95, . 849

FELLOWS DECEASED OR RESIGNED, 1894–95, ... 850

LIST OF ORDINARY FELLOWS ELECTED DURING SESSION 1895–96, . 851

FELLOWS DECEASED OR RESIGNED, 1895–96, ... 852

LAWS OF THE SOCIETY, ... 853

THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES, ... 860

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, AND NEILL PRIZES, FROM 1827 TO 1896, AND OF THE GUNNING VICTORIA JUBILEE PRIZE FROM 1884 TO 1896, ... 863

PROCEEDINGS OF THE STATUTORY GENERAL MEETINGS, 1894 AND 1895, . 871

LIST OF PUBLIC INSTITUTIONS AND INDIVIDUALS ENTITLED TO RECEIVE COPIES OF THE TRANSACTIONS AND PROCEEDINGS OF THE ROYAL SOCIETY, ... 875

INDEX, ... 882

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ALPHABETICAL LIST OF ORDINARY FELLOWS,

AND LIST OF HONORARY FELLOWS,

At January 1897.

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OF

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CORRECTED TO JANUARY 1897.

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N. ,, ,, ,, Neill Medal.
V. J. ,, ,, ,, the Gunning Victoria Jubilee Prize.
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1891		* Cooper, Charles A., 15 Charlotte Square, Edinburgh
1890	C.	* Copeland, Ralph, Ph.D., Astronomer-Royal for Scotland, and Professor of Practical Astronomy in the University of Edinburgh (VICE-PRESIDENT), Royal Observatory, Blackford Hill, Edinburgh 115
1879		* Cox, Robert, of Gorgie, M.A., M.P. for the Southern Division of Edinburgh, 34 Drumsheugh Gardens
1870		Crichton-Browne, Sir Jas., M.D., LL.D., F.R.S., Lord Chancellor's Visitor and Vice-President of the Royal Institution of Great Britain, 61 Carlisle Place Mansions, Victoria Street, and Royal Courts of Justice, Strand, London
1875		* Craig, William, M.D., F.R.C.S.E., Lecturer on Materia Medica to the College of Surgeons, 71 Bruntsfield Place

Date of Election.		
1887		* Crawford, William Caldwell, Lockharton Gardens, Slateford, Edinburgh
1886		* Croom, John Halliday, M.D., F.R.C.P.E., 25 Charlotte Square
1878		* Cunningham, Daniel John, M.D., D.C.L., F.R.S., F.Z.S., Professor of Anatomy in Trinity College, Dublin, 43 Fitzwilliam Place, Dublin
1871		Cunynghame, R. J. Blair, M.D., Vice-President of the Royal College of Surgeons, 18 Rothesay Place
1885		* Daniell, Alfred, M.A., LL.B., D.Sc., Advocate, 3 Great King Street
1884		Davy, Richard, F.R.C.S., Surgeon to the Westminster Hospital, Burstone House, Bow, North Devon
1894		* Denny, Archibald, Braehead, Dumbarton
1895		* Deuchar, David, F.I.A., F.F.A., Actuary, 12 Hope Terrace
1869	C.	Dewar, James, M.A., LL.D., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge, and Fullerian Professor of Chemistry at the Royal Institution of Great Britain, London
1884		* Dickson, Charles Scott, Advocate, Solicitor-General for Scotland, 4 Heriot Row
1888	C.	* Dickson, H. N., 2 St Margaret's Road, Oxford
1876	C.	* Dickson, J. D. Hamilton, M.A., Fellow and Tutor, St Peter's College, Cambridge
1885	C.	Dixon, James Main, M.A., Professor of English Literature in the Washington University of St Louis, United States
1881	C.	* Dobbin, Leonard, Ph.D., Assistant to the Professor of Chemistry in the University of Edinburgh, 7 Cobden Road
1867	C.	Donaldson, J., M.A., LL.D., Principal of the University of St Andrews, St Andrews
1896		* Donaldson, William, M.A., Viewpark House
1882	C.	* Dott, D. B., Memb. Pharm. Soc., 29 Spring Gardens, E.
1892		Doyle, Patrick, C.E., M.R.I.A., F.G.S., Editor of *Indian Engineering*, Calcutta
1866		Douglas, David, 22 Drummond Place
1880	C.	* Drummond, Henry, F.G.S., Professor of Natural History in the Free Church College, 2 Park Circus, Glasgow
1876		* Duncan, James, 9 Mincing Lane, London
1889		* Duncan, James Dalrymple, F.S.A. Lond. and Scot., Meiklewood, Stirling
1870		Duncan, John, M.A., M.D., LL.D., F.R.C.S.E., 8 Ainslie Place
1878		* Duncanson, J. J. Kirk, M.D., F.R.C.P.E., 22 Drumsheugh Gardens
1859	C.	Duns, Rev. Professor, D.D., New College, Edinburgh, 5 Greenhill Place
1892		Dunstan, M. J. R., B.A., F.C.S., Director of Technical Education in Agriculture, Newcastle Circus, The Park, Nottingham
1888		* Durham, James, F.G.S., Wingate Place, Newport, Fife
1893		Edington, Alexander, M.B., C.M., Colonial Bacteriologist, Graham's Town, South Africa
1869		Elder, George, Knock Castle, Wemyss Bay, Greenock
1885		Elgar, Francis, Memb. Inst. C.E., LL.D., F.R.S., 18 York Terrace, Regent's Park, London
1875		Elliot, Daniel G., Curator of the Department of Zoology, Field Columbian Museum, Chicago, U.S.
1855		Etheridge, Robert, F.R.S., Assistant-Keeper of the Geological Department at the British Museum of Natural History, 14 Carlyle Square, Chelsea, London
1884		* Evans, William, F.F.A., 18A Morningside Park
1863	C.	Everett, J. D., M.A., D.C.L., F.R.S., Professor of Natural Philosophy, Queen's College, Belfast
1879	C.	* Ewart, James Cossar, M.D., F.R.C.S.E., F.R.S., F.L.S., Professor of Natural History, University of Edinburgh

Date of Election.		
1878	C.	* Ewing, James Alfred, B.Sc., Memb. Inst. C.E., F.R.S., Professor of Mechanism and Applied Mechanics in the University of Cambridge, Langdale Lodge, Cambridge
1875		Fairley, Thomas, Lecturer on Chemistry, 8 Newton Grove, Leeds 155
1888	C.	* Fawsitt, Charles A., 9 Foremount Terrace, Dowanhill, Glasgow
1859		Fayrer, Sir Joseph, Bart., K.C.S.I., M.D., LL.D., F.R.C.P.L., F.R.C.S. L. and E., F.R.S., Honorary Physician to the Queen, 16 Devonshire Street, Portland Place, London, W.
1883	C.	* Felkin, Robert W., M.D., F.R.G.S., Fellow of the Anthropological Society of Berlin, 8 Alva Street
1888		* Ferguson, John, M.A., LL.D., Professor of Chemistry in the University of Glasgow
1868	C.	Ferguson, Robert M., LL.D., Ph.D., 3 Learmonth Terrace 160
1886		Field, C. Leopold, F.C.S., Upper Marsh, Lambeth, London
1852		Fleming, Andrew, M.D., Deputy Surgeon-General, 8 Napier Road
1876		* Fleming, J. S., 16 Grosvenor Crescent
1880		* Flint, Robert, D.D., Corresponding Member of the Institute of France, Corresponding Member of the Royal Academy of Sciences of Palermo, Professor of Divinity in the University of Edinburgh (Vice-President), Johnstone Lodge, 54 Craigmillar Park
1872	C.	Forbes, Professor George, M.A., Memb. Inst. C.E., M.S.T.E. and E., F.R.S., F.R.A.S., 34 Great George Street, Westminster 165
1892		* Ford, John Simpson, F.C.S., 11 Abbotsford Park
1859		Forlong, Major-Gen. J. G., F.R.G.S., R.A.S., Assoc. C.E., &c., 11 Douglas Crescent
1828		Foster, John, Liverpool
1887		Fowler, Sir John, Bart., K.C.M.G., Memb. Inst. C.E., LL.D., Thornwood Lodge, Kensington, London
1858		Fraser, A. Campbell, M.A., LL.D., D.C.L., Emeritus Professor of Logic and Metaphysics in the University of Edinburgh, Gorton House, Hawthornden 170
1896		* Fraser, John, M.B., F.R.C.P.E., one of H.M. Commissioners in Lunacy for Scotland, 19 Strathearn Road
1892		* Fraser, Patrick Neill, Rockville, Murrayfield
1867	K. B. C.	Fraser, Thomas R., M.D., F.R.C.P.E., LL.D., F.R.S., Professor of Materia Medica in the University of Edinburgh, 13 Drumsheugh Gardens
1891		* Fullarton, J. H., M.A., D.Sc., Zoologist to the Fishery Board for Scotland, 101 George Street
1891		* Fulton, T. Wemyss, M.B., Secretary for Scientific Investigations to the Scottish Fishery Board, 30 Dalhousie Terrace 175
1892		* Fyfe, Peter, Chief Sanitary Inspector, Glasgow
1888		* Galt, Alexander, B.Sc., F.C.S., Physical Laboratory, The University, Glasgow
1894		Gatty, Charles Henry, M.A., LL.D., F.L.S., Felbridge Place, East Grinstead
1867		Gayner, Charles, M.D., Oxford
1889		* Geddes, George H., Mining Engineer, 8 Douglas Crescent 180
1880	C.	* Geddes, Patrick, Professor of Botany in University College, Dundee, and Lecturer on Zoology, Ramsay Garden, University Hall, Edinburgh
1861	B. C.	Geikie, Sir Archibald, LL.D., D.Sc. Dub., F.R.S., F.G.S., Corresponding Member of the Institute of France, Corresponding Member of the Royal Academy of Berlin, Director of the Geological Surveys of Great Britain, and Head of the Geological Museum, 28 Jermyn Street, London
1871	B. C.	Geikie, James, LL.D., D.C.L., F.R.S., F.G.S., Professor of Geology in the University of Edinburgh (Vice-President), 31 Merchiston Avenue
1881		* Gibson, George Alexander, D.Sc., M.D., F.R.C.P.E., 17 Alva Street

Date of Election.		
1890		* Gibson, George A., M.A., Professor of Mathematics in the Glasgow and West of Scotland Technical College, 183 Renfrew Street, Glasgow 185
1877	C.	* Gibson, John, Ph.D., Professor of Chemistry in the Heriot-Watt College, 20 George Square
1892		Gifford, H. J., Walsingham House, Piccadilly, London, W.
1887		* Gilmour, William, 9 Inverleith Row
1880		* Gilruth, George Ritchie, Surgeon, 48 Northumberland Street
1850		Gosset, Major-General W. D., R.E., 70 Edith Road, West Kensington, London 190
1880		* Graham, James, LL.D., 198 West George Street, Glasgow
1891		* Graham, Richard D., 11 Strathearn Road
1883		* Gray, Andrew, M.A., LL.D., F.R.S., Professor of Physics in University College, Bangor, North Wales
1880	C.	Gray, Thomas, B.Sc., Prof. of Physics, Rose Polytechnic Institute, Terre Haute, Indiana, U.S.
1886		* Greenfield, W. S., M.D., F.R.C.P.E., Professor of General Pathology in the University of Edinburgh, 7 Heriot Row 195
1886	C	* Griffiths, Arthur Bower, Ph.D., Lecturer at the National Dental Hospital and College, London, 12 Knowle Road, Brixton, London
1883		Gunning, His Excellency Robert Halliday, Grand Dignitary of the Order of the Rose of Brazil, M.A., M.D., LL.D., 12 Addison Crescent, Kensington
1888	C.	Guppy, Henry Brougham, M.B., Craven Villa, Matlock Dale, Derbyshire
1867		Hallen, James H. B., C.I.E., F.R.C.S.E., Veterinary Lieut.-Colonel in H.M. Indian Army, Retired, Pebworth Fields, under Stratford-on-Avon
1881	C.	* Hamilton, D. J., M.B., F.R.C.S.E., Professor of Pathological Anatomy in the University of Aberdeen, 4 Forest Road, Aberdeen 200
1876	C.	* Hannay, J. Ballantyne, Cove Castle, Loch Long
1896		* Harris, David, Fellow of the Statistical Society, West Grange, Grange Loan, Edinburgh
1896	C.	* Harris, David Fraser, B.Sc., M.B., C.M., Assistant to the Professor of Physiology in the University of Glasgow, West Grange, Grange Loan, Edinburgh
1888		* Hart, D. Berry, M.D., F.R.C.P.E., 29 Charlotte Square
1869		Hartley, Sir Charles A., K.C.M.G., Memb. Inst. C.E., 26 Pall Mall, London 205
1877	C.	Hartley, W. N., F.R.S., Prof. of Chemistry, Royal College of Science for Ireland, Dublin
1881		* Harvie-Brown, J. A., of Quarter, Dunipace House, Larbert, Stirlingshire
1880	C.	* Haycraft, J. Berry, M.D., D.Sc., Professor of Physiology in the University College of South Wales and Monmouthshire, Cardiff
1892		* Heath, Thomas, B.A., Assistant Astronomer, Royal Observatory, Edinburgh
1862		Hector, Sir J., K.C.M.G., M.D., F.R.S., Director of the Geological Survey, Wellington, New Zealand 210
1876	K. C.	* Heddle, M. Forster, M.D., Emeritus Prof. of Chemistry in the University of St Andrews
1893		Hehir, Patrick, M.D., F.R.C.S.E., M.R.C.S.L., L.R.C.P.E., Surgeon-Captain, Indian Medical Service, Principal Medical Officer, H.H. the Nizam's Army, Hyderabad, Deccan, India
1890	C.	Helme, T. A., M.D., 258 Oxford Road, Manchester
1884		* Henderson, John, Meadowside Works, Partick, Glasgow
1890	C.	* Hepburn, David, M.D., Lecturer on Regional Anatomy in the University of Edin. 215
1896	C.	* Herbertson, Andrew J., Lecturer on Commercial Geography in the Heriot-Watt College, The Loan, Colinton
1881	N. C.	* Herdman, W. A., D.Sc., F.R.S., Prof. of Natural History in University College, Liverpool
1871		Higgins, Charles Hayes, M.D., M.R.C.P.L., F.R.C.S., Alfred House, Birkenhead

Date of Election.		
1894		Hill, Alfred, M.D., M.R.C.S., F.I.C., Medical Officer of Health, The Council House, Birmingham
1859		Hills, John, Major-General, C.B., Bombay Engineers, United Service Club, London, and Love's Grove, Aberystwith, Wales 220
1879		Hislop, John, LL.D., formerly Secretary to the Department of Education, Forth Street, Dunedin, New Zealand
1885		Hodgkinson, W. R., Ph.D., F.I.C., F.C.S., Professor of Chemistry and Physics at the Royal Military Academy and Royal Artillery College, Woolwich, 8 Park Villas, Blackheath, Kent
1881	N. C.	* Horne, John, F.G.S., Geological Survey of Scotland, Sheriff-Court Buildings, Edinburgh
1896		Horne, J. Fletcher, M.D., F.R.C.S.E., The Poplars, Barnsley
1893		Howden, Robert, M.B., C.M., Lecturer on Anatomy, University of Durham College of Medicine, Newcastle-on-Tyne 225
1883	C.	* Hoyle, William Evans, M.A., M.R.C.S., 25 Brunswick Road, Withington, Manchester
1886		Hunt, Rev. H. G. Bonavia, Mus. D. Dub., Mus. B. Oxon., F.L.S., La Belle Sauvage, London
1872		Hunter, Colonel Charles, of Pläs Cöch, Llanfairpwll, Anglesea, and Junior United Service Club, London
1887	C.	* Hunter, James, F.R.C.S.E., F.R.A.S., Rosetta, Liberton, Midlothian
1887	C.	* Hunter, William, M.D., M.R.C.P. L. and E., M.R.C.S., 54 Harley Street, London 230
1882		* Inglis, J. W., Memb. Inst. C.E., Kenwood, Liberton, Midlothian
1886	N. C.	* Irvine, Robert, Royston, Granton, Edinburgh
1875		Jack, William, M.A., LL.D., Professor of Mathematics in the University of Glasgow
1894		Jackson, Sir John, 10 Holland Park, London
1889	C.	* James, Alexander, M.D., F.R.C.P.E., 44 Melville Street 235
1882		* Jamieson, A., Memb. Inst. C.E., Professor of Engineering in The Glasgow and West of Scotland Technical College, Glasgow
1860	C.	Jamieson, George Auldjo, Actuary, 24 St Andrew Square
1880		Japp, A. H., LL.D., The Limes, Elmstead, near Colchester
1869		Johnston, John Wilson, M.D., Surgeon Lieut.-Colonel, Benmore, 30 Bidston Road, Oxton, Cheshire
1895		* Johnston, Surgeon-Major Henry Halcro, D.Sc., M.D., Orphir House, Kirkwall, Orkney 240
1867		Johnston, T. B., F.R.G.S., Geographer to the Queen, 9 Claremont Crescent
1874		Jones, Francis, Lecturer on Chemistry, Beaufort House, Alexandra Park, Manchester
1888		Jones, John Alfred, Memb. Inst. C.E., Vice-President, and Engineer, City of Madras, Peter's Road, Madras
1896		* Jong, E. F. de, L.R.C.P.E., L.R.C.S.E., F.R.C.V.S., Jock's Lodge, Edinburgh
1847	K. C. V. J.	Kelvin, The Right Hon. Lord, G.C.V., LL.D., D.C.L., F.R.S. (PRESIDENT), Grand Officer of the Legion of Honour of France, Member of the Prussian Order *Pour le Mérite*, Foreign Associate of the Institute of France, and Regius Professor of Natural Philosophy in the University of Glasgow 245
1892		* Kerr, Rev. John, M.A., Manse, Dirleton
1891		Kerr, Joshua Law, M.D., Croft House, Crawshawbooth, Manchester
1886	N. C.	* Kidston, Robert, F.G.S., 24 Victoria Place, Stirling
1877		* King, Sir James, of Campsie, Bart., LL.D., 115 Wellington Street, Glasgow
1880		* King, W. F., Lonend, Russell Place, Trinity 250

Date of Election.		
1886		* Kingsburgh, The Right Hon. Lord, C.B., Q.C., LL.D., F.R.S., M.S.T.E. and E., Lord Justice-Clerk, and Lord President of the Second Division of the Court of Session, 15 Abercromby Place
1883		* Kinnear, The Right Hon. Lord, one of the Senators of the College of Justice, 2 Moray Place
1878		* Kintore, The Right Hon. the Earl of, M.A. Cantab., Keith Hall, Inglismaldie Castle, Laurencekirk
1880	K. C.	* Knott, C. G., D.Sc., Lecturer on Applied Mathematics in the University of Edinburgh (late Prof. of Physics, Imperial University, Japan), 42 Upper Gray Street, Edinburgh
1896		* Kuenen, J. P., Ph.D. (Leiden), Prof. of Natural Philosophy in University College, Dundee 255
1886		* Laing, Rev. George P., 17 Buckingham Terrace
1878	C.	* Lang, P. R. Scott, M.A., B.Sc., Professor of Mathematics in the University of St Andrews
1885	C.	* Laurie, A. P., B.A., B.Sc., Woodside, Baldwin's Hill, Loughton
1894	C.	* Laurie, Malcolm, B.A., D.Sc., F.L.S., Professor of Zoology, St Mungo's College, Glasgow
1870		Laurie, Simon S., M.A., LL.D., Professor of Education in the University of Edinburgh, 22 George Square 260
1872		Lee, Alexander H., C.E., 58 Manor Place
1863		Leslie, Hon. G. Waldegrave, Leslie House, Leslie
1874	K. C.	* Letts, E. A., Ph.D., F.I.C., F.C.S., Professor of Chemistry, Queen's College, Belfast
1889		* Lindsay, Rev. James, B.D., B.Sc., F.G.S., Corresponding Member of the Royal Academy of Sciences, Letters and Arts, of Padua, Minister of St Andrew's Parish, Springhill Terrace, Kilmarnock
1870	B. C.	Lister, The Right Hon. Lord, M.D., F.R.C.S.L., F.R.C.S.E., LL.D., D.C.L., P.R.S., Foreign Associate of the Institute of France, Professor of Clinical Surgery, King's College, Surgeon Extraordinary to the Queen, 12 Park Crescent, Portland Place, London 265
1895		* Lothian, The Most Hon. The Marquis of, K.T., LL.D., Newbattle Abbey, Dalkeith
1884		* Low, George M., Actuary, 15 Chester Street
1888		* Lowe, D. F., M.A., Headmaster of Heriot's Hospital School, Lauriston
1849		Lowe, W. H., M.D., F.R.C.P.E., Woodcote, Inner Park, Wimbledon
1886		Lyster, George Fosbery, Memb. Inst. C.E., Gisburn House, Liverpool 270
1894		* Mabbott, Walter John, M.A., Rector of County High School, Duns, Berwickshire
1855		Macadam, Stevenson, Ph.D., Lecturer on Chemistry, Surgeons' Hall, Edinburgh, 11 East Brighton Crescent, Portobello
1888		* Macadam, W. Ivison, F.I.C., F.C.S., Lecturer on Chemistry, Slioch, Lady Road, Newington, Edinburgh
1887		M'Aldowie, Alexander M., M.D., 6 Brook Street, Stoke-on-Trent
1891		Macallan, John, F.I.C., 3 Charlemont Terrace, Clontarf, Dublin 275
1888	C.	M'Arthur, John, F.C.S., 196 Trinity Road, Wandsworth Common, London
1885		* M'Bride, Charles, M.D., Wigtown
1883		* M'Bride, P., M.D., F.R.C.P.E., 16 Chester Street
1867		M'Candlish, John M., W.S., 27 Drumsheugh Gardens
1894		* Macdonald, James, Secretary of the Highland and Agricultural Society of Scotland, 9 Lauriston Gardens 280
1886		* Macdonald, William J., M.A., Comiston Drive
1888	C.	* M'Fadyean, John, M.B., B.Sc., Professor of Pathology and Dean of the Royal Veterinary College, Camden Town, London
1878	C.	Macfarlane, Alexander, M.A., D.Sc., LL.D., Lecturer in Physics in Lehigh University, Pennsylvania

Date of Election.		
1885	C.	* Macfarlane, J. M., D.Sc., Professor of Biology in the University of Pennsylvania, Lansdowne, Delaware Co., Pennsylvania
1878		* M'Gowan, George, F.I.C., Ph.D., 1 Mount Avenue, Ealing, Middlesex 285
1886		* MacGregor, Rev. James, D.D., 3 Eton Terrace
1880	C.	MacGregor, J. G., M.A., D.Sc., Professor of Physics in Dalhousie College, Halifax, Nova Scotia
1869	N.C.	M'Intosh, William Carmichael, M.D., LL.D., F.R.S., F.L.S., Professor of Natural History in the University of St Andrews, 2 Abbotsford Crescent, St Andrews
1895	C.	* Macintyre, John, M.D., 179 Bath Street, Glasgow
1882		* Mackay, John Sturgeon, M.A., LL.D., Mathematical Master in the Edinburgh Academy, 69 Northumberland Street 290
1873	B. C.	* M'Kendrick, John G., M.D., F.R.C.P.E., LL.D., F.R.S. (Vice-President), Professor of Physiology in the University of Glasgow
1840		Mackenzie, John, New Club, Princes Street
1894		* Mackenzie, Robert, M.D., 1 Bruntsfield Terrace
1843	C.	Maclagan, Sir Douglas, M.D., F.R.C.P.E., LL.D., (Honorary Vice-President), Emeritus Professor of Medical Jurisprudence in the University of Edinburgh, 28 Heriot Row
1894		* Maclagan, Philip R. D., F.F.A. (Treasurer), St Catherine's, Liberton 295
1869		Maclagan, R. C., M.D., F.R.C.P.E., 5 Coates Crescent
1864		M'Lagan, Peter, of Pumpherston
1869	C.	M'Laren, The Hon. Lord, LL.D. Edin. and Glasg., F.R.A.S., one of the Senators of the College of Justice (Vice-President), 46 Moray Place
1888		* Maclean, Magnus, M.A., D.Sc., Lecturer on Physics in the University of Glasgow, 8 St Alban's Terrace, Dowanhill, Glasgow
1876		* Macleod, Rev. Norman, D.D., Westwood, Inverness 300
1883		* Macleod, W. Bowman, L.D.S., 16 George Square
1896		* M'Lintock, James, M.D., B.Sc., Member of the Local Government Board of Scotland, 5 Atholl Crescent
1872		Macmillan, Rev. Hugh, D.D., LL.D., 70 Union Street, Greenock
1876		* Macmillan, John, M.A., D.Sc., M.B., C.M., F.R.C.P.E., 27 Warrender Park Road
1893		* M'Murtrie, The Rev. John, M.A., D.D., 5 Inverleith Place 305
1884		* Macpherson, Rev. J. Gordon, M.A., D.Sc., Ruthven Manse, Meigle
1888		Mactear, James, F.C.S., 2 Victoria Mansions, Hyde Park, London
1890		* M'Vail, John C., M.D., 2 Strathallan Terrace, Dowanhill, Glasgow
1880	C.	Marsden, R. Sydney, M.B., C.M., D.Sc., F.I.C., F.C.S., 64 Park Road, South, and Town Hall, Birkenhead
1882	C.	Marshall, D. H., M.A., Professor of Physics in Queen's University and College, Kingston, Ontario, Canada 310
1869		Marshall, Henry, M.D., Clifton, Bristol
1888	C.	* Marshall, Hugh, D.Sc., Assistant to the Professor of Chemistry in the University of Edinburgh, 131 Warrender Park Road
1892		* Martin, Francis John, W.S., 9 Glencairn Crescent
1864		Marwick, Sir James David, LL.D., Town-Clerk, Glasgow
1866		Masson, David, LL.D., Litt.D. Dub., Professor of Rhetoric and English Literature in the Univ. of Edinburgh, Her Majesty's Historiographer for Scotland, 110 Princes Street 315
1885	C.	* Masson, Orme, D.Sc., Professor of Chemistry in the University of Melbourne
1890		* Matheson, The Rev. George M.A., B.D., D.D., Minister of St Bernard's, Edinburgh, 19 St Bernard's Crescent

Date of Election.		
1888		* Methven, C. W., Memb. Inst. C.E., Engineer-in-Chief to the Natal Harbour Board, Equitable Buildings, Durban
1885	B. C.	* Mill, Hugh Robert, D.Sc., Librarian, Royal Geographical Society, 1 Saville Row, London
1833		Milne, Admiral Sir Alexander, Bart., G.C.B., Inveresk 320
1886		* Milne, William, M.A., B.Sc., 57 Springbank Terrace, Aberdeen
1866		Mitchell, Sir Arthur, K.C.B., M.A., M.D., LL.D., 34 Drummond Place
1889	C.	* Mitchell, A. Crichton, D.Sc., Professor of Pure and Applied Mathematics, and Principal of the Maharajah's College, Trivandrum, Travancore, India
1865		Moir, John J. A., M.D., F.R.C.P.E., 52 Castle Street
1871		Moncrieff, Rev. Canon William Scott, of Fossaway, Easington Rectory, Castle Eden, County Durham 325
1890	C.	Mond, R. L., M.A. Cantab., F.C.S., 20 Avenue Road, Regent's Park, London
1868		Montgomery, Very Rev. Dean, M.A., D.D., 17 Atholl Crescent
1887		Moos, N. A. F., L.C.E., B.Sc., Assistant Prof. of Engineering, College of Science, Bombay
1896		* Morgan, Alexander, M.A., B.Sc., 6 Cluny Terrace
1892		Morrison, J. T., M.A., B.Sc., Professor of Physics and Chemistry, Victoria College, Stellenbosch, Cape Colony 330
1892	C.	* Mossman, Robert C., 10 Blacket Place
1874	K. C.	* Muir, Thomas, M.A., LL.D., Superintendent-General of Education for Cape Colony, Education Office, and The Hall, Mowbray, Cape Town
1888		* Muirhead, George, Mains of Haddo, Aberdeen
1887		Mukhopâdhyay, Âsûtosh, M.A., LL.D., F.R.A.S., M.R.I.A., Professor of Mathematics at the Indian Association for the Cultivation of Science, 77 Russa Road North, Bhowanipore, Calcutta
1870		Munn, David, M.A., 1 Albyn Place 335
1894		* Munro, J. M. M., M.I.E.E., 136 Bothwell Street, Glasgow
1889		* Munro, Rev. Robert, M.A., B.D., F.S.A. Scot., Free Church Manse, Old Kilpatrick
1891	C.	* Munro, Robert, M.A., M.D., Hon. Memb. R.I.A., Hon. Memb. Royal Soc. of Antiquaries of Ireland, Secretary of the Society of Antiquaries of Scotland, 48 Manor Place
1896		* Murray, Alfred A., M.A., LL.B., 20 Warriston Crescent
1892	C.	* Murray, George Robert Milne, F.R.S., F.L.S., Keeper of the Botanical Department, British Museum, (Natural Hist.), Cromwell Road, London 340
1857		Murray, John Ivor, M.D., F.R.C.S.E., M.R.C.P.E., 24 Huntriss Row, Scarborough
1877	B. N. C.	* Murray, John, LL.D., Ph.D., D.Sc., F.R.S. (SECRETARY), (Society's Representative on George Heriot's Trust), Director of the Challenger Expedition Publications. Office, 45 Frederick St. House, Challenger Lodge, Wardie, Edin., and United Service Club
1888		* Murray, R. Milne, M.A., M.B., F.R.C.P.E., 11 Chester Street
1887		Muter, John, M.A., F.C.S., South London Central Public Laboratory, 325 Kennington Road, London
1888		Napier, A. D. Leith, M.D., C.M., M.R.C.P.L., 67 Grosvenor St., Grosvenor Sq., London 345
1895		* Napier, James, M.A., Drums, Old Kilpatrick
1877		* Napier, John, C. Audley Mansions, Grosvenor Square, London
1887		* Nasmyth, T. Goodall, M.D., C.M., D.Sc., Cupar-Fife
1883		* Newcombe, Henry, F.R.C.S.E., 5 Dalrymple Crescent, Edinburgh
1884		* Nicholson, J. Shield, M.A., D.Sc., Professor of Political Economy in the University of Edinburgh, 3 Belford Park 350
1880	C.	* Nicol, W. W. J., M.A., D.Sc., 15 Blacket Place

Date of Election.		
1878		Norris, Richard, M.D., M.R.C.S. Eng., 67 Broad Street, Birmingham
1888		* Ogilvie, F. Grant, M.A., B.Sc., Principal of the Heriot-Watt College
1888		* Oliphant, James, M.A., 11 Ramsay Gardens
1886	C.	Oliver, James, M.D., F.L.S., Physician to the London Hospital for Women, 18 Gordon Square, London 355
1895		Oliver, Thomas, M.D., F.R.C.P., Professor of Physiology in the University of Durham, 7 Ellison Place, Newcastle-upon-Tyne
1884	K. C.	* Omond, R. Traill, Superintendent of Ben Nevis Observatory, Fort-William, Inverness, and 43 Charlotte Square, Edinburgh
1877		Panton, George A., 73 Westfield Road, Edgbaston, Birmingham
1892		Parker, Thomas, Memb. Inst. C.E., Newbridge House, Wolverhampton
1886	C.	* Paton, D. Noël, M.D., B.Sc., F.R.C.P.E., 33 George Square 360
1889		* Patrick, David, M.A., LL.D., c/o W. & R. Chambers, 339 High Street
1892		* Paulin, David, 6 Forres Street
1881	N.C.	* Peach, B. N., F.R.S., F.G.S., Acting Palæontologist of the Geological Survey of Scotland, 86 Findhorn Place
1889		* Peck, William, F.R.A.S., Town's Astronomer, Murrayfield, Edinburgh
1863		Peddie, Alexander, M.D., F.R.C.P.E., 15 Rutland Street 365
1887	C.	* Peddie, Wm., D.Sc., Assistant to the Professor of Natural Philosophy, Edinburgh University, 2 Cameron Park
1886		* Peebles, D. Bruce, Tay House, Bonnington, Edinburgh
1893		Perkin, Arthur George, 8 Montpellier Terrace, Hyde Park, Leeds
1889		* Philip, R. W., M.A., M.D., F.R.C.P.E., 4 Melville Crescent
1883		Phillips, Charles D. F., M.D., LL.D., 10 Henrietta St., Cavendish Sq., London, W. 370
1859	C.	Playfair, The Right Hon. Lord, G.C.B., LL.D., F.R.S., 68 Onslow Gardens, London
1877	C.	Pole, William, Memb. Inst. C.E., Mus. Doc., F.R.S., Athenæum Club, London
1886		* Pollock, Charles Frederick, M.D., F.R.C.S.E., 1 Buckingham Terrace, Hillhead, Glasgow
1874		Powell, Baden Henry Baden-, C.I.E., M.R.A.S., Forest Department, India
1852		Powell, Eyre B., C.S.I., M.A., 28 Park Road, Haverstock Hill, Hampstead, London 375
1888		Prain, David, Surgeon, Indian Medical Service, and Curator of the Herbarium, Royal Botanic Gardens, Shibpur, Calcutta
1892		* Pressland, Arthur, M.A., Camb., Edinburgh Academy
1875	C.	Prevost, E. W., Ph.D., Elton, Newnham, Gloucester
1849		Primrose, Hon. B. F., C.B., 22 Moray Place
1885		* Pullar, J. F., Rosebank, Perth 380
1880		* Pullar, Sir Robert, Tayside, Perth
1884		Ramsay, E. Peirson, M.R.I.A., F.L.S., C.M.Z.S., F.R.G.S., F.G.S., Fellow of the Imperial and Royal Zoological and Botanical Society of Vienna, Curator of Australian Museum, Sydney, N.S.W.
1891		* Rankine, John, M.A., LL.D., Advocate, Professor of the Law of Scotland in the University of Edinburgh, 23 Ainslie Place
1885	C.	* Rattray, John, M.A., B.Sc., Dunkeld
1883	C.	* Readman, J. B., D.Sc., F.C.S., 4 Lindsay Place, Edinburgh 385
1889		Redwood, Boverton, F.I.C., F.C.S., Assoc. Inst. C.E., Glenwathen, Ballard's Lane, Finchley, Middlesex
1875		* Richardson, Ralph, W.S., 10 Magdala Place
1872		Ricarde-Seaver, Major F. Ignacio, Athenæum Club, Pall Mall, London

Date of Election.		
1883		* Ritchie, R. Peel, M.D., F.R.C.P.E., President of the Scottish Microscopical Society, 1 Melville Crescent
1880		Roberts, D. Lloyd, M.D., F.R.C.P.L., 23 St John Street, Manchester 390
1872		Robertson, D. M. C. L. Argyll, M.D., LL.D., F.R.C.S.E., Surgeon Oculist to the Queen for Scotland, 18 Charlotte Square
1886		* Robertson, Right Hon. J. P. B., Q.C., LL.D., Lord Justice-General of Scotland and Lord President of the Court of Session, 19 Drumsheugh Gardens
1896		* Robertson, Robert, M.A., 27 Hartington Place, Viewforth
1896	C.	* Robertson, W. G. Aitchison, D.Sc., M.D., F.R.C.P.E., 26 Minto Street
1877	C.	* Robinson, George Carr, F.I.C., F.C.S., Lecturer on Chemistry in the College of Chemistry, Royal Institution, Hull 395
1881		* Rogerson, John Johnston, B.A., LL.B., LL.D., Merchiston Castle Academy
1881		Rosebery, The Right Hon. the Earl of, K.G., K.T., LL.D., Dalmeny Park, Edinburgh
1880		Rowland, L. L., M.A., M.D., President of the Oregon State Medical Society, and Professor of Physiology and Microscopy in Williamette University, Salem, Oregon
1880		* Russell, Sir James Alex., M.A., B.Sc., M.B., F.R.C.P.E., LL.D., Woodville, Canaan Lane
1869	C.	Rutherford, Wm., M.D., F.R.C.P.E., F.R.S., Professor of Physiology in the University of Edinburgh, 14 Douglas Crescent 400
1864		Sandford, The Right Rev. Bishop D. F., LL.D., Boldon Rectory, Newcastle-on-Tyne
1895		Savage, Thomas, M.D., F.R.C.S. England, M.R.C.P. London, Professor of Gynæcology, Mason College, Birmingham, The Ards, Knowle, Warwickshire
1891		Sawyer, Sir James, Knt., M.D., F.R.C.P., J.P., Consulting Physician to the Queen's Hospital, Haseley Hall, Warwick
1885	C.	Scott, Alexander, M.A., D.Sc., St Peter's College, Cambridge
1880		Scott, J. H., M.B., C.M., M.R.C.S., Prof. of Anatomy in the University of Otago, N.Z. 405
1888		* Scott, John, C.B., Memb. Inst. C.E., Halkshill, Largs, Ayrshire
1875		Scott, Michael, Memb. Inst. C.E., care of A. Grahame, Esq., 30 Great George Street, Westminster
1889		* Scougal, Andrew E., M.A., H.M. Inspector of Schools, 12 Blantyre Terrace
1872	C.	Seton, George, M.A., Advocate, Ayton House, Abernethy, Perthshire
1894		* Shield, Wm., M.Inst.C.E., Executive Engineer, National Harbour of Refuge, Peterhead 410
1872		Sibbald, John, M.D., Comr. in Lunacy, 18 Great King Street
1870		Sime, James, M.A., Craigmount House, 52 Dick Place
1871		Simpson, A. R., M.D., President of the Royal College of Physicians, Professor of Midwifery in the University of Edinburgh, 52 Queen Street
1888		* Sinclair, D. S., 370 Great Western Road, Glasgow
1876		* Skinner, William, W.S., 35 George Square 415
1868		Smith, Adam Gillies, C.A., Agsacre, North Berwick
1891	C.	* Smith, Alex., B.Sc., Ph.D., Prof. of General Chemistry, University of Chicago, Ills., U.S.
1882	C.	Smith, C. Michie, B.Sc., F.R.A.S., Professor of Physical Science, Christian College, and Officiating Government Astronomer, Madras, India
1885		* Smith, George, F.C.S., Polmont Station
1883		Smith, James Greig, M.A., M.B., 16 Victoria Square, Clifton 420
1871	C.	Smith, John, M.D., F.R.C.S.E., LL.D., 11 Wemyss Place
1880		Smith, William Robert, M.D., D.Sc., Barrister-at-Law, Professor of Forensic Medicine in King's College, 74 Great Russell Street, Bloomsbury Square, London

Date of Election.		
1846	K. B. C.	Smyth, Piazzi, LL.D., Ex-Astronomer-Royal for Scotland, and Emeritus Professor of Astronomy in the University of Edinburgh, Clova, Ripon
1880		Sollas, W. J., M.A., D.Sc., F.R.S., late Fellow of St John's College, Cambridge, and Professor of Geology and Mineralogy in the University of Dublin, Lisnabin, Dartry Park Road, Rathgar, county Dublin
1889	C.	* Somerville, William, Dr Oec., B.Sc., Professor of Agriculture and Forestry in the Durham College of Science, Newcastle-upon-Tyne 425
1882		* Sorley, James, F.I.A., C.A., 32 Onslow Square, London
1896		* Spence, Frank, M.A., B.Sc., 76 Marchmont Crescent
1874	C.	* Sprague, T. B., M.A., LL.D., Actuary, 29 Buckingham Terrace
1891		* Stanfield, Richard, Professor of Mechanics and Engineering in the Heriot-Watt College
1886	C.	* Stevenson, Charles A., B.Sc., Memb. Inst. C.E., 28 Douglas Crescent 430
1884		* Stevenson, David Alan, B.Sc., Memb. Inst. C.E., 45 Melville Street
1877		* Stevenson, James, F.R.G.S., Largs
1888		* Stevenson, Rev. John, LL.D., Minister of Glamis, Forfarshire
1868		Stevenson, John J., 4 Porchester Gardens, London
1888	C.	* Stewart, Charles Hunter, D.Sc., M.B., C.M., 3 Carlton Terrace 435
1868		Stewart, Major-General J. H. M. Shaw, late R.E., Assoc. Inst. C.E., F.R.G.S., 61 Lancaster Gate, London, W.
1866	C.	Stewart, Sir Thomas Grainger, M.D. Edin. and Dub., F.R.C.P.E., LL.D., Professor of the Practice of Physic in the University of Edinburgh, 19 Charlotte Square
1873		* Stewart, Walter, 1 Murrayfield Gardens
1877		* Stirling, William, D.Sc., M.D., Brackenbury Professor of Physiology and Histology in Owens College and Victoria University, Manchester
1889	C.	* Stockman, Ralph, M.D., F.R.C.P.E., 12 Hope Street 440
1894		* Struthers, John, M.D., LL.D., Emeritus Professor of Anatomy in the University of Aberdeen, 24 Buckingham Terrace
1823		Stuart, Captain T. D., H.M.I.S.
1896		* Sutherland, John Francis, M.D., Deputy Com. in Lunacy for Scotland, 4 Merchiston Bank Avenue
1875		* Syme, James, 10 George Street
1885	C.	* Symington, Johnson, M.D., F.R.C.S.E., Prof. of Anatomy in Queen's College, Belfast 445
1872		Tait, The Venerable A., D.D., LL.D., M.R.I.A., Archdeacon of Tuam, Moylough Rectory, Ballinasloe, County Galway, Ireland
1861	K. C. V. J.	Tait, P. Guthrie, M.A., D.Sc., Professor of Natural Philosophy in the University of Edinburgh (GENERAL SECRETARY), 38 George Square
1895		Talmage, James Edward, Ph.D., D.Sc., Pres. of the Univ. of Utah, Salt Lake City, Utah
1890	C.	Tanakadate, Aikitu, Professor of Natural Philosophy in the Imperial University of Japan, Tokyo, Japan
1870		Tatlock, Robert R., F.C.S., City Analyst's Office, 156 Bath Street, Glasgow 450
1892		* Taylor, W. A., M.A. (Camb.), 3 East Mayfield
1872		Teape, Rev. Charles R., M.A., Ph.D., 15 Findhorn Place
1892		* Thackwell, J. B., M.B., C.M., Tenterfield, New South Wales
1885	C.	* Thompson, D'Arcy W., B.A., F.L.S., Professor of Natural History in University College, Dundee
1884		* Thoms, George Hunter, of Aberlemno, Advocate, Sheriff of the Counties of Orkney and Zetland, 13 Charlotte Square 455

Date of Election.		
1870		Thomson, Rev. Andrew, D.D., 63 Northumberland Street
1887		* Thomson, Andrew, M.A., D.Sc., Mathematical Master in the Perth Academy, 10 Pitcullen Terrace, Perth
1887	C.	* Thomson, J. Arthur, M.A., Lecturer on Zoology, School of Medicine, 11 Ramsay Gardens
1880		Thomson, John Millar, F.R.S., 85 Addison Road, London
1896		* Thomson, George Ritchie, M.B., C.M., 306 Bath Street, Glasgow 460
1870		Thomson, Spencer C., Actuary, 10 Eglinton Crescent
1882		Thomson, Wm., M.A., B.Sc., Registrar, University of the Cape of Good Hope, University Chambers, Cape Town
1876		Thomson, William, Royal Institution, Manchester
1893		* Tillie, Joseph, M.D., C.M., 10 Castle Terrace
1874	N. C.	* Traquair, R. H., M.D., LL.D., F.R.S., F.G.S., Keeper of the Natural History Collection in the Museum of Science and Art, Edinburgh, 8 Dean Park Crescent 465
1874		* Tuke, J. Batty, M.D., F.R.C.P.E., 20 Charlotte Square
1888		* Turnbull, Andrew H., Actuary, The Elms, Whitehouse Loan
1861	N. C.	Turner, Sir William, M.B., LL.D., D.C.L., D.Sc. Dub., F.R.C.S.E., F.R.S., Professor of Anatomy in the University of Edinburgh, 6 Eton Terrace
1895		* Turton, Albert H., F.C.S., F.R.G.S., Ashleigh, Carlyle Road, Edgbaston, Birmingham
1877		* Underhill, Charles E., B.A., M.B., F.R.C.P.E., F.R.C.S.E., 8 Coates Crescent 470
1889		Underhill, T. Edgar, M.D., F.R.C.S.E., Broomsgrove, Worcestershire
1891		Vernon, Henry Hannotte, M.D., 7 Talbot Street, Southport, Lancashire
1875		Vincent, Charles Wilson, F.I.C., F.C.S., M.R.I., Librarian of the Reform Club, Pall Mall, 38 Queen's Road, South Hornsey, Middlesex
1888		Walker, James, Memb. Inst. C.E., Engineer's Office, Harbour Works, Douglas, Isle of Man
1891	B. C.	* Walker, James, D.Sc., Ph.D., Professor of Chemistry in University College, Dundee, 8 Windsor Terrace, Dundee 475
1873	C.	* Walker, Robert, M.A., University, Aberdeen
1886	C.	* Wallace, R., F.L.S., Prof. of Agriculture and Rural Economy in the Univ. of Edinburgh
1891		* Walmsley, R. Mullineux, D.Sc., Principal of the Northampton Institute, Clerkenwell, London
1866		Watson, Patrick Heron, M.D., F.R.C.S.E., LL.D., 16 Charlotte Square
1862	C.	Watson, Rev. Robert Boog, B.A., LL.D., F.L.S., President of the Conchological Society, Free Church Manse, Cardross, Dumbartonshire 480
1887		* Webster, H. A., Librarian to the University of Edinburgh, 3 John Street, Portobello
1896		* Webster, John Clarence, B.A., M.D., F.R.C.P.E., 287 Mountain Street, Montreal, Canada
1882		* Wenley, James A., Treasurer of the Bank of Scotland, 5 Drumsheugh Gardens
1896		Wenley, R. M., M.A., D.Sc., D.Phil., Professor of Philosophy in the University of Michigan, U.S.
1896	C.	White, Philip J., M.B., Prof. of Zoology in University College, Bangor, North Wales 485
1890		White, Sir William Henry, K.C.B., LL.D., F.R.S., Memb. Inst. C.E., Assistant Controller of the Navy, and Director of Naval Construction, The Admiralty, London
1881		Whitehead, Walter, F.R.C.S.E., Professor of Clinical Surgery, Owens College and Victoria University, 499 Oxford Road, Manchester
1894		Whymper, Edward, 29 Ludgate Hill, London
1883		Wickham, R. H. B., M.D., F.R.C.S.E., Medical Superintendent, City and County Lunatic Asylum, Newcastle-on-Tyne, West Mead, Dawlish, South Devon
1879		* Will, John Charles Ogilvie, M.D., 379 Union Street, Aberdeen 490

Date of Election.		
1868		Williams, W., Principal and Professor of Veterinary Medicine and Surgery, New Veterinary College, Leith Walk
1888		* Williamson, George, F.A.S. Scot., 37 Newton Street, Finnart, Greenock
1879		* Wilson, Andrew, Ph.D., F.L.S., Lecturer on Zoology and Comparative Anatomy, 110 Gilmore Place
1895		Wilson-Barker, David, F.R.G.S., F.R. Met. Soc., Captain-Superintendent Thames Nautical Training College, H.M.S. "Worcester," Greenhithe, Kent
1878	C.	* Wilson, Rev. John, M.A., 23 Buccleuch Place 495
1882		Wilson, George, M.A., M.D., 7 Avon Place, Warwick
1891		* Wilson, John Hardie, D.Sc., The Yorkshire College, Leeds
1889		Wilson, Robert, Memb. Inst. C.E., St Stephen's Club, and 7 Westminster Chambers, Victoria Street, London
1870		Winzer, John, Chief Surveyor, Civil Service, Ceylon, Southfield, Paignton, S. Devon
1886	C.	* Woodhead, German Sims, M.D., F.R.C.P.E., Director of the Laboratories of the Royal Colleges of Physicians (Lond.) and Surgeons (Eng.), Examination Hall, Victoria Embankment, W.C., and 1 Nightingale Lane, Balham, London, S.W. 500
1884		Woods, G. A., M.R.C.S., 16 Adelaide Road, Leamington
1890		* Wright, Johnstone Christie, care of J. Barker Duncan, 6 Hill Street
1896		* Wright, Robert Patrick, Professor of Agriculture, West of Scotland Technical College, Glasgow, Laventille, Crow Road, Partick, Glasgow
1882		* Young, Frank W., F.C.S., Lecturer on Natural Science, High School, Dundee, Woodmuir Park, West Newport, Fife
1892	C.	Young, George, Ph.D., Firth College, Sheffield
1896	C.	* Young, James Buchanan, M.B., D.Sc., 35 Montague Street
1882		* Young, Thomas Graham, Westfield, West Calder 507

LIST OF HONORARY FELLOWS

At March 1897.

His Royal Highness The Prince of Wales.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.).

Elected.		
1897	Alexander Agassiz,	*Cambridge (Mass.).*
1897	E.-H. Amagat,	*Paris.*
1889	Marcellin Pierre Eugène Berthelot,	*Paris.*
1895	Ludwig Boltzmann,	*Vienna.*
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1897	Stanislao Cannizzaro,	*Rome.*
1883	Luigi Cremona,	*Rome.*
1877	Carl Gegenbaur,	*Heidelberg.*
1888	Ernst Haeckel,	*Jena.*
1883	Julius Hann,	*Vienna.*
1884	Charles Hermite,	*Paris.*
1879	Jules Janssen,	*Paris.*
1864	Albert von Kölliker,	*Würzburg.*
1864	Rudolph Leuckart,	*Leipzig.*
1897	Gabriel Lippmann,	*Paris.*
1895	Éleuthère-Élie-Nicolas Mascart,	*Paris.*
1888	Demetrius Ivanovich Mendeléef,	*St Petersburg.*
1895	Carl Menger,	*Vienna.*
1886	Alphonse Milne-Edwards	*Paris.*
1864	Theodore Mommsen,	*Berlin.*
1897	Fridtjof Nansen,	*Christiania.*
1881	Simon Newcomb,	*Washington.*
1895	Max von Pettenkofer,	*Munich.*
1895	Jules Henri Poincaré,	*Paris.*
1889	Georg Hermann Quincke,	*Heidelberg.*
1886	Alphonse Renard,	*Ghent.*
1897	Ferdinand von Richthofen,	*Berlin.*
1897	Henry A. Rowland,	*Baltimore.*
1897	Giovanni V. Schiaparelli,	*Milan.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen.*
1878	Otto Wilhelm Struve,	*St Petersburg.*
1886	Tobias Robert Thalén,	*Upsala.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1892	Gustav Wiedemann,	*Leipzig.*
1897	Ferdinand Zirkel,	*Leipzig.*

Total, 36.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected.		
1889	Sir Robert Stawell Ball, Kt., LL.D., F.R.S., M.R.I.A., Lowndean, Professor of Astronomy in the University of Cambridge,	*Cambridge*
1897	The Very Rev. John Caird, D.D., LL.D., Principal of the University of Glasgow,	*Glasgow.*
1892	Colonel Alexander Ross Clarke, C.B., R.E., F.R.S.,	*Redhill, Surrey*
1897	George Howard Darwin, M.A., LL.D., F.R.S., Plumian Professor of Astronomy in the University of Cambridge,	*Cambridge.*
1895	Sir J. William Dawson, C.M.G., LL.D., F.R.S.,	*Montreal.*
1897	Sir William Flower, K.C.B., LL.D., D.C.L., F.R.S., Director of the Natural History Department, British Museum,	*London.*
1884	Edward Frankland, D.C.L., LL.D., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1892	David Gill, LL.D., F.R.S., Her Majesty's Astronomer at the Cape of Good Hope,	*Cape of Good Hope.*
1895	Albert C. L. G. Günther, Ph.D., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., M.D., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1884	William Huggins, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1892	Sir James Paget, Bart., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1886	The Lord Rayleigh, D.C.L., LL.D., D.Sc. Dub., Sec. R.S., Corresp. Mem. Inst. of France,	*London.*
1881	The Rev. George Salmon, D.D., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*Dublin.*
1884	J. S. Burdon Sanderson, M.D., LL.D., D.Sc. Dub., F.R.S.,	*Oxford.*
1864	Sir George Gabriel Stokes, Bart., M.P., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*Cambridge.*
1892	The Right Rev. W. Stubbs, D.D., LL.D., Bishop of Oxford,	*Oxford.*
1874	James Joseph Sylvester, LL.D., F.R.S., Corresp. Mem. Inst. of France,	*Oxford.*
1895	Sir Charles Todd, K.C.M.G., F.R.S., Government Astronomer, South Australia,	*Adelaide.*
1883	Alexander William Williamson, LL.D., F.R.S., Corresp. Mem. Inst. of France,	*London.*

Total, 20.

ORDINARY FELLOWS ELECTED

During Session 1894–95.

Arranged according to the Date of their Election.

3rd December 1894.

Robert Gervase Alford, M. Inst. C.E. James Edward Talmage, D.Sc., Ph.D

7th January 1895.

Charles Bright, Assoc. M. Inst. C.E. Albert H. Turton, F.C.S.

4th February 1895.

The Most Hon. The Marquis of Lothian, K.T. John Macintyre, M.D.
Surgeon-Major Henry Halcro Johnston, D.Sc., M.D.

4th March 1895.

Professor Thomas Oliver, M.D., F.R.C.P.

1st April 1895.

David Deuchar, F.I.A., F.F.A. James Napier, M.A.
George Sandeman, M.A.

3rd June 1895.

Professor Thomas Savage, M.D., F.R.C.S. Captain David Wilson-Barker, F.R. Met. Soc.

1st July 1895.

Edwin H. Barton, D.Sc.

FELLOWS DECEASED OR RESIGNED

DURING SESSION 1894–95.

ORDINARY FELLOWS DECEASED.

Dr T. A. G. BALFOUR, F.R.C.P.E.
Professor JOHN S. BLACKIE.
BENJAMIN CARRINGTON, M.D. (died 18th Jan. 1893).
HUGH F. C. CLEGHORN of Stravithie, M.D., LL.D.
PETER DENNY, LL.D., Memb. Inst. C.E.
PATRICK DUDGEON of Cargen.
The Right Hon. LORD MONCREIFF of Tulliebole, LL.D. (HONORARY VICE-PRESIDENT).
ALEXANDER GOODMAN MORE, M.R.I.A.
JOHN SHAND, M.D., F.R.C.P.E.
MURRAY THOMSON, M.D.
The Rev. THOMAS HARDIE TURNBULL.

RESIGNED.

Dr A. S. CUMMING.
GEORGE M. CUNNINGHAM.
R. J. HARVEY GIBSON.
JOHN S. YEO.

HONORARY FELLOWS DECEASED

SESSION 1894–95.

FORIEGN.

JAMES D. DANA.
LUDVIG SVEN LOVÉN.
LOUIS PASTEUR.

BRITISH.

Professor CAYLEY.
Professor T. H. HUXLEY.

ORDINARY FELLOWS ELECTED

During Session 1895–96.

Arranged according to the Date of their Election

6th January 1896.

J. O. Affleck, M.D., F.R.C.P.E.
Prof. D. Campbell Black, M.D., F.F.P.S. Glas.
Andrew J. Herbertson.
Professor J. P. Kuenen, Ph.D.
Robert Robertson, M.A.
John Francis Sutherland, M.D.
John Clarence Webster, B.A., M.D., F.R.C.P.E.
Professor Robert Patrick Wright.

3rd February 1896.

W. J. Aitchison Robertson, D.Sc., M.D., F.R.C.P.E.

2nd March 1896.

Professor Matthew Charteris, M.D.
Frank Spence, M.A.
Professor Philip J. White, M.B.

6th April 1896.

J. W. Butters, M.A., B.Sc.
William Donaldson, M.A.
John Fraser, M.B., F.R.C.P.E.
James M'Lintock, M.D., B.Sc.

4th May 1896.

Professor Francis Gibson Baily, M.A.
Alexander Morgan, M.A., B.Sc.
George Ritchie Thomson, M.B., C.M.
James Buchanan Young, M.B., D.Sc.

1st June 1896.

David Harris.
David Fraser Harris, B.Sc., M.B., C.M.
J. Fletcher Horne, M.D., F.R.C.S.E.
E. F. de Jong, L.R.C.P. and S., Ed., F.R.C.V.S.

6th July 1896.

Alfred A. Murray, M.A., LL.B.
Professor R. M. Wenley, M.A., D.Sc., D.Phil.

FELLOWS DECEASED OR RESIGNED

DURING SESSION 1895–96.

ORDINARY FELLOWS DECEASED.

JAMES ABERNETHY, Memb. Inst. C.E.
Sir THOMAS DAWSON BRODIE, Bart.
The Rev. J. GIBSON CAZENOVE, M.A., D.D.
DAVID CUNNINGHAM, Memb. Inst. C.E.
JOHN GRIEVE, M.A., M.D.
ROBERT LAWSON, M.D.
JOSIAH LIVINGSTON.
GEORGE M'ROBERTS, F.C.S.
HUGH MILLER.
JAMES CLERK RATTRAY, M.D.
Rev. THOMAS MILVILLE RAVEN, M.A.
GEORGE ROBERTSON, Memb. Inst. C.E.
ROBERT MACFIE THORBURN.

RESIGNED.

GEORGE SANDEMAN.
Sir W. J. BELL.
Professor PERKIN.

HONORARY FELLOWS DECEASED.

SESSION 1895–96.

FOREIGN.

ERNST CURTIUS.
GABRIEL AUGUSTE DAUBRÉE.
ARMAND HIPPOLYTE LOUIS FIZEAU.
AUGUST KEKULÉ.
HUBERT A. NEWTON.

BRITISH.

Sir WILLIAM ROBERT GROVE.
JOHN RUSSELL HIND.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH,

AS REVISED 20TH FEBRUARY 1882.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

Title.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows.

II.

The fees of Ordinary Fellows residing in Scotland.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.*

III.

Payment to cease after 25 years.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from further payment.

IV.

Fees of Non-Resident Ordinary Fellows.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt

* A modification of this rule, in certain cases, was agreed to at a Meeting of the Society held on the 3rd January 1831.

At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s. to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

Case of Fellows becoming Non-Resident.

from any further payment. In the case of any Resident Fellow ceasing to reside in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

Defaulters.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

Privileges of Ordinary Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

Numbers Unlimited.

The number of Ordinary Fellows shall be unlimited.

VIII.

Fellows entitled to Transactions.

The Ordinary Fellows, upon producing an order from the Treasurer, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

Mode of Recommending Ordinary Fellows.

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall afterwards be printed in the circulars for three Ordinary Meetings of the Society, previous to the day of election, and shall lie upon the table during that time.

* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being "to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby "recommend him as deserving of that honour, and as likely to prove a useful and valuable Member."

X.

Honorary Fellows shall not be subject to any contribution. This class shall consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states.

Honorary Fellows, British and Foreign.

XI.

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X.

Royal Personages.

XII.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two ordinary meetings of the Society, previous to the day of election.

Recommendation of Honorary Fellows.

Mode of Election.

XIII.

The election of Ordinary Fellows shall only take place at the first Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote.

Election of Ordinary Fellows.

XIV.

The Ordinary Meetings shall be held on the first and third Mondays of every month from December to July inclusively; excepting when there are five Mondays in January, in which case the Meetings for that month shall be held on its third and fifth Mondays. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make.

Ordinary Meetings.

* We hereby recommend_____
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

_____

_____

_____

To the President and Council of the Royal Society of Edinburgh.

XV.

The Transactions.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

The Council shall have power to regulate the private business of the Society. At any Meeting of the Council the Chairman shall have a casting as well as a deliberative vote.

XVI.

How Published.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

The Council.

That there shall be formed a Council, consisting—First, of such gentlemen as may have filled the office of President; and Secondly, of the following to be annually elected, viz.:—a President, Six Vice-Presidents (two at least of whom shall be resident), Twelve Ordinary Fellows as Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

Retiring Councillors.

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

Election of Office-Bearers.

An Extraordinary Meeting for the Election of Office-Bearers shall be held on the fourth Monday of November annually.

XX.

Special Meetings; how called.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

Treasurer's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in November, he shall present the accounts for the preceding year, duly audited.

At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in November, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings.

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the proceedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations, as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES.

The above Prizes will be awarded by the Council in the following manner:—

I. KEITH PRIZE.

The KEITH PRIZE, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1897–98 for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1895–96 and 1896–97." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL-BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1898–99, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 8th July 1898.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets, superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1896–97, 1897–98, whether they may have been given in with a view to the prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr PATRICK NEILL of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The NEILL PRIZE, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1898–99.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 8th July 1898,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

IV. GUNNING VICTORIA JUBILEE PRIZE.

This Prize, founded in the year 1887 by Dr R. H. GUNNING, is to be awarded triennially by the Council of the Royal Society of Edinburgh, in recognition of original work in Physics, Chemistry, or Pure or Applied Mathematics.

Evidence of such work may be afforded either by a Paper presented to the Society, or by a Paper on one of the above subjects, or some discovery in them elsewhere communicated or made, which the Council may consider to be deserving of the Prize.

The Prize consists of a sum of money, and is open to men of science resident in or connected with Scotland. The first award was made in the year 1887.

In accordance with the wish of the Donor, the Council of the Society may on fit occasions award the Prize for work of a definite kind to be undertaken during the three succeeding years by a scientific man of recognised ability.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES, FROM 1827 TO 1896.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2nd Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3rd Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor J. D. Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor James David Forbes, for his papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15th Biennial Period, 1855–57.—Professor Boole, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16th Biennial Period, 1857–59.—Not awarded.

17th Biennial Period, 1859–61.—John Allan Broun, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18TH BIENNIAL PERIOD, 1861–63.—Professor WILLIAM THOMSON, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19TH BIENNIAL PERIOD, 1863–65.—Principal FORBES, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society.

20TH BIENNIAL PERIOD, 1865–67.—Professor C. PIAZZI SMYTH, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21ST BIENNIAL PERIOD, 1867–69.—Professor P. G. TAIT, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22ND BIENNIAL PERIOD, 1869–71.—Professor CLERK MAXWELL, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23RD BIENNIAL PERIOD, 1871–73.—Professor P. G. TAIT, for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24TH BIENNIAL PERIOD, 1873–75.—Professor CRUM BROWN, for his Researches "on the Sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25TH BIENNIAL PERIOD, 1875–77.—Professor M. FORSTER HEDDLE, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26TH BIENNIAL PERIOD, 1877–79.—Professor H. C. FLEEMING JENKIN, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II. having appeared in the volume for 1877–78.

27TH BIENNIAL PERIOD, 1879–81.—Professor GEORGE CHRYSTAL, for his paper "on the Differential Telephone," published in the Transactions of the Society.

28TH BIENNIAL PERIOD, 1881–83.—THOMAS MUIR, Esq., LL.D., for his "Researches into the Theory of Determinants and Continued Fractions," published in the Proceedings of the Society.

29TH BIENNIAL PERIOD, 1883–85.—JOHN AITKEN, Esq., for his paper "on the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena, published in the Transactions of the Society.

30TH BIENNIAL PERIOD, 1885–87.—JOHN YOUNG BUCHANAN, Esq., for a series of communications, extending over several years, on subjects connected with Ocean Circulation, Compressibility of Glass, &c.; two of which, viz., "On Ice and Brines," and "On the Distribution of Temperature in the Antarctic Ocean," have been published in the Proceedings of the Society.

31ST BIENNIAL PERIOD, 1887–89.—Professor E. A. LETTS, for his Papers on the Organic Compounds of Phosphorus, published in the Transactions of the Society.

32ND BIENNIAL PERIOD, 1889–91.—R. T. OMOND, Esq., for his Contributions to Meteorological Science, many of which are contained in Vol. XXXIV. of the Society's Transactions.

33RD BIENNIAL PERIOD, 1891–93.—Professor THOMAS R. FRASER, F.R.S., for his Papers on *Strophanthus hispidus*, Strophanthin, and Strophanthidin, read to the Society in February and June 1889 and in December 1891, and printed in Vols. XXXV., XXXVI., and XXXVII. of the Society's Transactions.

34TH BIENNIAL PERIOD, 1893–95.—Dr CARGILL G. KNOTT, for his papers on the Strains produced by Magnetism in Iron and in Nickel, which have appeared in the Transactions and Proceedings of the Society.

II. MAKDOUGALL-BRISBANE PRIZE.

1st Biennial Period, 1859.—Sir Roderick Impey Murchison, on account of his Contributions to the Geology of Scotland.

2nd Biennial Period, 1860–62.—William Seller, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3rd Biennial Period, 1862–64.—John Denis Macdonald, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4th Biennial Period, 1864–66.—Not awarded.

5th Biennial Period, 1866–68.—Dr Alexander Crum Brown and Dr Thomas Richard Fraser, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6th Biennial Period, 1868–70.—Not awarded.

7th Biennial Period, 1870–72.—George James Allman, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8th Biennial Period, 1872–74.—Professor Lister, for his paper "on the Germ Theory of Putrefaction and the Fermentive Changes," communicated to the Society, 7th April 1873.

9th Biennial Period, 1874–76.—Alexander Buchan, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10th Biennial Period, 1876–78.—Professor Archibald Geikie, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

11th Biennial Period, 1878–80.—Professor Piazzi Smyth, Astronomer-Royal for Scotland, for his paper "on the Solar Spectrum in 1877–78, with some Practical Idea of its probable Temperature of Origination," published in the Transactions of the Society.

12th Biennial Period, 1880–82.—Professor James Geikie, for his "Contributions to the Geology of the North-West of Europe," including his paper "on the Geology of the Faroes," published in the Transactions of the Society.

13th Biennial Period, 1882–84.—Edward Sang, Esq., LL.D., for his paper "on the Need of Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor," and generally for his Recalculation of Logarithms both of Numbers and Trigonometrical Ratios, —the former communication being published in the Proceedings of the Society.

14th Biennial Period, 1884–86.—John Murray, Esq., LL.D., for his papers "On the Drainage Areas of Continents, and Ocean Deposits," "The Rainfall of the Globe, and Discharge of Rivers," "The Height of the Land and Depth of the Ocean," and "The Distribution of Temperature in the Scottish Lochs as affected by the Wind."

15th Biennial Period, 1886–88.—Archibald Geikie, Esq., LL.D., for numerous communications, especially that entitled "History of Volcanic Action during the Tertiary Period in the British Isles," published in the Transactions of the Society.

16th Biennial Period, 1888–90.—Dr Ludwig Becker, for his Paper on "The Solar Spectrum at Medium and Low Altitudes," printed in Vol. XXXVI. Part I. of the Society's Transactions.

17TH BIENNIAL PERIOD, 1890–92.—HUGH ROBERT MILL, Esq., D.Sc., for his Papers on "The Physical Conditions of the Clyde Sea Area," Part I. being already published in Vol. XXXVI. of the Society's Transactions.

18TH BIENNIAL PERIOD, 1892–94.—Professor JAMES WALKER, D.Sc., Ph.D., for his work on Physical Chemistry, part of which has been published in the Proceedings of the Society, Vol. XX., pp. 255–263. In making this award, the Council took into consideration the work done by Professor Walker along with Professor Crum Brown on the Electrolytic Synthesis of Dibasic Acids, published in the Transactions of the Society.

19TH BIENNIAL PERIOD, 1894–96.—Professor JOHN G. M'KENDRICK, for numerous Physiological papers, especially in connection with Sound; many of which have appeared in the Society's publications.

III. THE NEILL PRIZE.

1ST TRIENNIAL PERIOD, 1856–59.—Dr W. LAUDER LINDSAY, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2ND TRIENNIAL PERIOD, 1859–62.—ROBERT KAYE GREVILLE, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3RD TRIENNIAL PERIOD, 1862–65.—ANDREW CROMBIE RAMSAY, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and Memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geographical Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4TH TRIENNIAL PERIOD, 1865–68.—Dr WILLIAM CARMICHAEL M'INTOSH, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5TH TRIENNIAL PERIOD, 1868–71.—Professor WILLIAM TURNER, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6TH TRIENNIAL PERIOD 1871–74.—CHARLES WILLIAM PEACH, Esq., for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7TH TRIENNIAL PERIOD, 1874–77.—Dr RAMSAY H. TRAQUAIR, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton), published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

8TH TRIENNIAL PERIOD, 1877–80.—JOHN MURRAY, Esq., for his paper "on the Structure and Origin of Coral Reefs and Islands," published (in abstract) in the Proceedings of the Society.

9TH TRIENNIAL PERIOD, 1880–83.—Professor HERDMAN, for his papers "on the Tunicata," published in the Proceedings and Transactions of the Society.

10TH TRIENNIAL PERIOD, 1883–86.—B. N. PEACH, Esq., for his Contributions to the Geology and Palæontology of Scotland, published in the Transactions of the Society.

11TH TRIENNIAL PERIOD, 1886–89.—ROBERT KIDSTON, Esq., for his Researches in Fossil Botany, published in the Transactions of the Society.

12TH TRIENNIAL PERIOD, 1889–92.—JOHN HORNE, Esq., F.G.S., for his Investigations into the Geological Structure and Petrology of the North-West Highlands.

13TH TRIENNIAL PERIOD, 1892–95.—ROBERT IRVINE, Esq., for his papers on the action of Organisms in the Secretion of Carbonate of Lime and Silica, and on the solution of these substances in Organic Juices. These are printed in the Society's Transactions and Proceedings.

IV. GUNNING VICTORIA JUBILEE PRIZE.

1ST TRIENNIAL PERIOD, 1884–87.—Sir WILLIAM THOMSON, Pres. R.S.E., F.R.S., for a remarkable series of papers "on Hydrokinetics," especially on Waves and Vortices, which have been communicated to the Society.

2ND TRIENNIAL PERIOD, 1887–90.—Professor P. G. TAIT, Sec. R.S.E., for his work in connection with the "Challenger" Expedition, and his other Researches in Physical Science.

3RD TRIENNIAL PERIOD, 1890–93.—ALEXANDER BUCHAN, Esq., LL.D., for his varied, extensive, and extremely important Contributions to Meteorology, many of which have appeared in the Society's Publications.

4TH TRIENNIAL PERIOD, 1893–96.—JOHN AITKEN, Esq., for his brilliant Investigations in Physics, especially in connection with the Formation and Condensation of Aqueous Vapour.

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PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS,

26TH NOVEMBER 1894,

AND

25TH NOVEMBER 1895.

STATUTORY MEETING.

HUNDRED AND TWELFTH SESSION.

Monday, 26th November 1894.

At the Annual Statutory Meeting,

Sir DOUGLAS MACLAGAN, M.D., President, in the Chair,

The Minutes of last Annual Statutory Meeting of 27th November 1893 were read, approved, and signed.

Drs SMITH and BALFOUR were requested to act as Scrutineers in the Ballot for the New Council.

Read Letter of Resignation by the TREASURER, and Letter of Council in reply.

On the motion of the CHAIRMAN, seconded by Dr BUCHAN, a cordial vote of thanks was passed to Dr GILLIES SMITH for his many services to the Society.

The Annual Accounts were submitted and approved.

The Auditor's Report was read and approved.

The Scrutineers reported that the following Council had been duly elected:—

Sir DOUGLAS MACLAGAN, M.D., F.R.C.P.E., President.

Sir WM. TURNER, LL.D., D.C.L., F.R.S.,
Professor RALPH COPELAND, Ph.D., Astronomer-Royal for Scotland,
Professor JAMES GEIKIE, LL.D., D.C.L., F.R.S.,
The Hon. Lord MACLAREN, LL.D., F.R.A.S.,
The Rev. Professor FLINT, D.D.,
Professor JOHN G. M'KENDRICK, M.D., LL.D., F.R.S.,
} Vice-Presidents.

Professor P. G. TAIT, M.A., D.Sc., General Secretary.

Professor CRUM BROWN, F.R.S.,
JOHN MURRAY, LL.D.,
} Secretaries to Ordinary Meetings.

PHILIP R. D. MACLAGAN, F.F.A., Treasurer.

ALEXANDER BUCHAN, M.A., LL.D., Curator of Library and Museum.

COUNCILLORS.

Professor D'Arcy W. Thompson, B.A., F.L.S.	A. Beatson Bell, Advocate.
Professor J. Shield Nicholson, M.A., D.Sc.	Sir Arthur Mitchell, K.C.B., LL.D.
Professor George Chrystal, M.A., LL.D.	Professor T. R. Fraser, LL.D., F.R.S.
J. Batty Tuke, M.D., F.R.C.P.E.	Robert Munro, M.A., M.D.
Alexander Bruce, M.A., M.D.	D. Noël Paton, B.Sc., M.D.
Professor Fred. O. Bower, M.A., F.R.S.	Cargill G. Knott, D.Sc.

The Scrutineers were thanked for their services by the Chairman.

On the motion of Mr Cox, the Auditor was thanked and reappointed.

On the motion of Professor Tait, the Chairman was thanked for his conduct in the chair.

Douglas Maclagan, *P.*

STATUTORY MEETING.

HUNDRED AND THIRTEENTH SESSION.

Monday, 25th November 1895.

At the Annual Statutory Meeting,

Sir DOUGLAS MACLAGAN, M.D., President, in the Chair,

The Minutes of last Annual Statutory Meeting of 26th November 1894 were read, approved, and signed.

Mr SKINNER and Mr OMOND were appointed Scrutineers, and the Ballot for the New Council commenced.

The TREASURER submitted his Annual Accounts for the year with the Auditors' Report, which were read and approved.

The Scrutineers reported that the following New Council had been duly elected :—

The Right Hon. Lord KELVIN, LL.D., D.C.L., F.R.S., President.

Professor RALPH COPELAND, Astronomer-Royal for Scotland,
Professor JAMES GEIKIE, LL.D., F.R.S.,
The Hon. Lord M'LAREN, LL.D., F.R.A.S.,
The Rev. Professor FLINT, D.D.,
Professor JOHN G. M'KENDRICK, M.D., LL.D., F.R.S.,
Professor GEORGE CHRYSTAL, M.A., LL.D.,
} Vice-Presidents.

Professor P. G. TAIT, M.A., D.Sc., General Secretary.

Professor CRUM BROWN, F.R.S.,
JOHN MURRAY, LL.D.,
} Secretaries to Ordinary Meetings.

PHILIP R. D. MACLAGAN, F.F.A., Treasurer.

ALEXANDER BUCHAN, M.A., LL.D., Curator of Library and Museum.

COUNCILLORS.

ALEXANDER BRUCE, M.A., M.D., F.R.C.P.E.
Professor FREDERICK O. BOWER, M.A., F.R.S.
A. BEATSON BELL, Advocate.
Sir ARTHUR MITCHELL, K.C.B., LL.D.
Professor THOMAS R. FRASER, M.D., LL.D., F.R.S.
ROBERT MUNRO, M.A., M.D.
D. NOËL PATON, B.Sc., M.D., F.R.C.P.E.
CARGILL G. KNOTT, D.Sc.
Sir WILLIAM TURNER, LL.D., D.C.L., F.R.S.
Sir STAIR AGNEW, K.C.B., M.A.
JAMES BURGESS, C.I.E., LL.D., M.R.A.S.
JOHN STURGEON MACKAY, M.A., LL.D.

On the motion of Mr SKINNER, seconded by Dr CRUM BROWN, the thanks of the Society were given to the Treasurer.

Dr CRUM BROWN proposed, seconded by Dr MUNRO, a vote of thanks to the Scrutineers.

Mr BELL moved, and Professor TAIT seconded, a special vote to the retiring President (the Chairman), who in returning thanks called attention to the award of a Royal Medal to Dr JOHN MURRAY.

The AUDITOR was thanked for his Report and reappointed.

A. CAMPBELL FRASER, D.C.L.,
Chairman.

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... Chemical Society, Burlington House.
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... Naturhistorisches Museum.
Helsingfors, Sällskapet pro Fauna et Flora Fennica.
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Moscow, Société Impériale des Naturalistes de Moscou.
... Société Impériale des Amis d'Histoire Naturelle, d'Anthropologie et d'Ethnographie.
... Musée Polytechnique.
... L'Observatoire Impérial.
Munich, Königlich-Bayerische Akademie der Wissenschaften (2 copies).
Nantes, Société des Sciences de l'Ouest de la France.
Naples, Zoological Station, Dr Anton Dohrn.
... Società Reale di Napoli—Accademia delle Scienze Fisiche e Matematiche.
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Neufchatel, Société des Sciences Naturelles.
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ASIA.

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Delft, École Polytechnique.
Dijon, Académie des Sciences.
Erlangen, Physico-Medical Society.
Frankfurt a. Oder, Naturwissenschaftlicher Verein.
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Toulouse, Académie des Sciences.
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Japan, The Asiatic Society of Japan.
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New York, The American Museum of Natural History.
... American Geographical Society.
... American Mathematical Society.
Philadelphia, Wagner Free Institute of Science.
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Texas, Academy of Science, Austin.
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Rio de Janeiro, Museu Nacional.
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Santiago, Deutscher Wissenschaftlicher Verein.

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INDEX.

A

Acanthotelson, 799.

Agrigentum, Decadrachm of, 187.

AHMES, the Egyptian Mathematician. His Symbol and Name for an Unknown Quantity was Hau =a Heap. See under Diophantus, 608.

Amphibians, Development of Müllerian Duct of. By GREGG WILSON, M.A., B.Sc., 509.

Amphipolis, Coin of, 184.

Anæmia in Dogs, 298; *in Rabbits*, 310.

Anaspides, The Genus and Affinities of. By W. T. CALMAN, 787. Antenna of, 789. First Maxilla of, 790. Mandible of, 790. Thoracic Limbs of, 791. Systematic Position of, 794.

Apes (Anthropoid), Palmar Interosseous Muscles of, 557.

Ardlamont Point, Temperature of, 56.

ARGYLL (HIS GRACE THE DUKE OF). Two Glens and the Agency of Glaciation, 193–202.

Arran Basin, Temperature of, 44.

Aspidites silesiacus, 210.

B

BARTON (EDWIN H.), D.Sc. The Temperature Variation of the Magnetic Permeability of Magnetite, 567–578.

BEATTIE (Dr J. C.). Experiments on the Transverse Effect and on some Related Actions in Bismuth, 225–240.

—— On the Relation between the Variation of Resistance in Bismuth in a Steady Magnetic Field and the Rotatory or Transverse Effect, 241–251.

—— On the Curves of Magnetisation for Films of Iron, Cobalt, and Nickel, 757–764.

Bird and Beast in Ancient Symbolism. By Professor D'ARCY W. THOMPSON, 179.

Bismuth. Experiments on the Transverse Effect and on some Related Actions in Bismuth. By J. C. BEATTIE, 225.

—— Relation between the Variation of Resistance in Bismuth in a Steady Magnetic Field and the Rotatory or Transverse Effect. By J. C. BEATTIE, 241.

BUCHAN (ALEX.), LL.D. Specific Gravities and Oceanic Circulation, 317–342.

C

CALMAN (W. T.), B.Sc. On the Genus Anaspides and its Affinities with Certain Fossil Crustacea, 787–802.

Carradale, Temperature of, 46.

Chimæra monstrosa, Cranial Nerves of, with a Discussion of the Lateral Line System, and of the Morphology of the *Chorda tympani*. By FRANK J. COLE, 631. Sensory Canals of, 640. Nerves of, 642, 644, 651, 653, 664, 666, 672.

Chorda Tympani of Chimæra monstrosa, 631.

CHRYSTAL (Professor GEORGE), LL.D. A Fundamental Theorem regarding the Equivalence of Systems of Ordinary Linear Differential Equations, and its Application to the Determination of the Order and the Systematic Solution of a Determinate System of such Equations, 163–178.

—— On the *p*-discriminant of a Differential Equation of the First Order, and on Certain Points in the General Theory of Envelopes connected therewith, 803–824.

Climatic Characteristics of the Months at Edinburgh, 696.

Clyde Sea Area, Mean Temperature of Air over. By HUGH ROBERT MILL, D.Sc., 12.

Cobalt Films, Curves of Magnetisation for. By Dr J. C. BEATTIE, 757.

COLE (FRANK J.). The Cranial Nerves of *Chimæra monstrosa* (Linn. 1754); with a Discussion of the Lateral Line System, and of the Morphology of the *Chorda tympani*, 631–680.

Colour-Blindness, A Case of. Part I. By WILLIAM PEDDIE, D.Sc., 501.

Cranial Nerves of Chimæra monstrosa. By FRANK J. COLE, 631.

CRŒSUS, Coin of, 183.

Cyatheites dentatus, 209.

D

Dactylotheca, 205.
Delphi, Coin of, 184.
Diagonal System, Properties of. By Professor CHRYSTAL, 169.
Diatoms of the Kerguelen Region, 472.
Dichromasy, A Case of (in Colour-Blindness), 501, 507.
DIOPHANTUS. On the Symbol ς′ or ς″, for an Unknown Quantity used by Diophantus in his Algebraic Problems. By Professor D'ARCY THOMPSON, 607.
Discriminant of a Differential Equation of the First Order. By Professor G. CHRYSTAL, 803.
Draco and the Two Bears, on an Asiatic gem, 190.
Dunoon Basin, Temperature of, 144.

E

Ear in Man, Cat, and Rabbit, 781.
Edinburgh, Meteorology of. By ROBERT COCKBURN MOSSMAN, 681. Mean Barometric Pressure of, 684. Temperature of, 686. Direction of the Wind, 691, 695. Rainfall, 691. Sunshine, 693. Auroras, 694. Snow, 694. Hail, 694. Thunderstorms, 694. Fogs or Mists, 695. Gales, 695.
Envelopes, Theory of, connected with the *p*-discriminant of a Differential Equation of the First Order. By Professor G. CHRYSTAL, 803.
Epidemics of Influenza in Edinburgh, 586.
Equations. Theorem regarding the Equivalence of Systems of Ordinary Linear Differential Equations. By Professor G. CHRYSTAL, LL.D., 163.
—— On the *p*-discriminant of a Differential Equation of the First Order, and on Certain Points in the General Theory of Envelopes connected therewith. By Professor G. CHRYSTAL, 803.
Equivalence of Systems of Ordinary Linear Differential Equations and its Application to the Determination of the Order and Systematic Solution of a Determinate System of such Equations. By Professor G. CHRYSTAL, LL.D., 163.
Eretria, Tetradrachm of, 185.

F

Filicites plumosus, 208.
Foraminifera of the Kerguelen Region, 458.
Fossil Flora of the Yorkshire Coal Field. By ROBERT KIDSTON, 203.
Fyne (Loch), Temperature of, 83.

G

Gampsonyx, 798.
Gareloch, Temperature of, 103.
Garroch Head, Temperature of, 52.
GILLESPIE (A. LOCKHART), M.D. The Weather, Influenza, and Disease; from the Records of the Edinburgh Royal Infirmary for Fifty Years, 579–606.
Glaciation. Two Glens and the Agency of Glaciation, 193.
Glenaray, Glaciation of, 196.
Glenshira, Glaciation of, 196.
Goil (Loch), Temperature of, 123.

H

Hæmorrhage, Effects of, 310.
Hand (human), Dorsal Interosseous Muscles of. By DAVID HEPBURN, M.D., 557.
HEPBURN (DAVID), M.D. A Revised Description of the Dorsal Interosseous Muscles of the Human Hand, with Suggestions for a New Nomenclature of the Palmar Interosseous Muscles and some Observations on the corresponding Muscles in the Anthropoid Apes, 557–565.
Hermitage Museum in St Petersburg, Cybele Relief in, 180.

I

Inchmarnock Water, Temperature of, 56.
Influenza and Disease, from the Records of the Edinburgh Royal Infirmary for Fifty Years. By A. LOCKHART GILLESPIE, M.D., 579.
Inveraray and Strachur, Temperature of, 80.
—— Glaciation of, 196.
Iron Films, Curves of Magnetisation for. By Dr J. C. BEATTIE, 757.
Iron, Steel, and Nickel Tubes, Strains in, produced in the Magnetic Field. By Professor KNOTT, D.Sc., 527.

K

Kerguelen Region of the Great Southern Ocean, The Deep and Shallow Water Marine Fauna of. By JOHN MURRAY, LL.D., of the "Challenger" Expedition. Metazoa, 353–450. Foraminifera, 458. Radiolaria, 468. Diatoms, 472. Surface Organisms, 477.
KIDSTON (ROBERT). On the Fossil Flora of the Yorkshire Coal Field. (First Paper), 203–223.
KNOTT (CARGILL G.), D.Sc. The Strains produced in Iron, Steel, and Nickel Tubes in the Magnetic Field. Part I., 527–555.

L

Lateral Line System of Chimæra monstrosa, 631.

M

M'KENDRICK (Professor JOHN G.). Observations on the Phonograph, 765. Resonators, 765. Parabolic Reflector, 767. Taking of Records, 767, 775. Mechanism of Recording Point, 768. Casts, 771. Photographs, 772. Tracing of Curves, 773. Intensity of Sounds, 775. Discrimination of Auditory Sensations, 779.

Magnetisation. Curves of Magnetisation for Films of Iron, Cobalt, and Nickel. By Dr J. C. BEATTIE, 757.

Magnetite. The Temperature Variation of the Magnetic Permeability of Magnetite. By EDWIN H. BARTON, D.Sc., 567.

Metazoa of the Kerguelen Region, 353.

Meteorology of Edinburgh. Part I. By ROBERT COCKBURN MOSSMAN, 681.

MILL (HUGH ROBERT), D.Sc. The Clyde Sea Area. Part III.—Distribution of Temperature, 1–161.

MOSSMAN (ROBERT COCKBURN). The Meteorology of Edinburgh. Part I., 681–755.

Müllerian Duct of Amphibians, The Development of. By GREGG WILSON, M.A., B.Sc., 509.

MURRAY (JOHN), LL.D., of the "Challenger" Expedition. On the Deep and Shallow Water Marine Fauna of the Kerguelen Region of the Great Southern Ocean, 343–500. List of Metazoa procured by the "Challenger" at various Depths, 353–450. Lists of the Foraminifera in the deposits from the Kerguelen Region at various Depths, 458. List of the Radiolaria observed at the "Challenger" Station in the Southern Indian Ocean, 468. List of the Diatoms observed in the Kerguelen Region, 472. List of Surface Organisms recorded during the cruise of the "Challenger" in the Kerguelen Region, 477.

N

Nickel Films, Curves of Magnetisation for. By Dr J. C. BEATTIE, 757.

Nickel Tubes in the Magnetic Field, 527.

O

Oceanic Circulation and Specific Gravities. By ALEXANDER BUCHAN, LL.D., 317–342. *Salinities*, 333, 334, 339.

Oceanic Prevailing Winds in January and July, 320, 321.

P

Palæocaris, 796.

Palmar Interosseous Muscles, New Nomenclature of. By DAVID HEPBURN, M.D., 557.

Parthian Gem, 185.

Pecopteris, 205.

PEDDIE (WILLIAM), D.Sc. On a Case of Colour-Blindness. Part I., 501–508.

—— The Torsional Oscillations of Wires, 611–630.

R

Radiolaria of the Southern Indian Ocean, 468.

Red Sea, Mean Annual Temperature and Specific Gravity of, 327.

S

Salinity of the Ocean, 320, 333, 334.

Schizopteris, 210.

Sigma (ς) *of Diophantus.* By Professor D'ARCY WENTWORTH THOMPSON, 607.

Skate Island, Temperature of, 57.

Specific Gravities and Oceanic Circulation. By ALEXANDER BUCHAN, LL.D., 317–342.

Spleen. Comparative Histology and Physiology of the Spleen. By A. J. WHITING, M.D., 253.

Spleen (in Leucocythæmia), 298.

Splenic Arteries and Splenic Follicles, 260, 269.

Splenic Ellipsoids, 269.

Splenic Pulp, 275.

Steel Tubes in the Magnetic Field, 527.

Strains produced in Iron, Steel, and Nickel Tubes in the Magnetic Field. By Professor C. G. KNOTT, D.Sc., 527.

Strivan (Loch), Temperature of, 136.

Symbolism. Bird and Beast in Ancient Symbolism. By Professor D'ARCY W. THOMPSON, 179.

T

Temperature Variation of the Magnetic Permeability of Magnetite. By EDWIN H. BARTON, D.Sc., 567.

THOMPSON (Professor D'ARCY WENTWORTH). On Bird and Beast in Ancient Symbolism, 179–192.

—— The ς of Diophantus, 607–609.

Torsional Oscillations of Wires. By Dr W. PEDDIE, 611. Existence of a Critical Angle, 619.

Transverse Effect in Bismuth, 225. Effects other than the Transverse Effect, 236. By J. C. BEATTIE.

W

Weather, Influenza, and Disease. By A. Lockhart Gillespie, M.D., 579–606.

Whiting (A. J.), M.D. On the Comparative Histology and Physiology of the Spleen, 253–316. The supporting Framework of the Spleen, 254. The Adenoid Sheath of the Splenic Arteries and the Splenic Follicles, 260. The Ellipsoidal Sheath of the Splenic Arteries and the Splenic Ellipsoids, 269. The Splenic Pulp, 275. The Physiology of the Spleen and Blood Formation, 296.

Wilson (Gregg), B.Sc. The Development of the Müllerian Duct of Amphibians, 509–526.

Wires, Torsional Oscillations of. By Dr W. Peddie, 611–630.

Y

Yorkshire Coal Field, Fossil Flora of. By Robert Kidston, 203–223.

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VOL. XXXVIII. PART I.—FOR THE SESSION 1894–95.

CONTENTS.

PAGE

I. *The Clyde Sea Area.* By HUGH ROBERT MILL, D.Sc., F.R.S.E. (Plates I.–XXXII.)
Part III.—*Distribution of Temperature,* 1
(*Issued separately, November 13th,* 1894.)

II. *A Fundamental Theorem regarding the Equivalence of Systems of Ordinary Linear Differential Equations, and its Application to the Determination of the Order and the Systematic Solution of a Determinate System of such Equations.* By GEORGE CHRYSTAL, M.A., LL.D., Professor of Mathematics in the University of Edinburgh, . 163
(*Issued separately, May 5th,* 1895.)

III. *On Bird and Beast in Ancient Symbolism.* By Professor D'ARCY WENTWORTH THOMPSON, Jr., ... 179
(*Issued separately, August 3rd,* 1895.)

IV. *Two Glens and the Agency of Glaciation.* By HIS GRACE THE DUKE OF ARGYLL, K.G., K.T. (With a Map), ... 193
(*Issued separately, September 20th,* 1895.)

V. *On the Fossil Flora of the Yorkshire Coal Field.* (First Paper.) By ROBERT KIDSTON, F.R.S.E., F.G.S. (Plates I.–III.), ... 203
(*Issued separately, February 5th,* 1896.)

VI. *Experiments on the Transverse Effect and on some Related Actions in Bismuth.* By J. C. BEATTIE. (With a Plate), ... 225
(*Issued separately, October 10th,* 1895.)

VII. *On the Relation between the Variation of Resistance in Bismuth in a Steady Magnetic Field and the Rotatory or Transverse Effect.* By J. C. BEATTIE. (With a Plate), . . . 241
(*Issued separately, December 7th,* 1895.)

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Part 2.	0 10 0	0 7 6
Part 3.	0 7 0	0 5 3
Part 4.	0 18 0	0 13 6
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Part 2.	0 10 0	0 7 6
Part 3.	1 5 0	1 1 0
XXIII. Part 1.	0 15 0	0 11 6
Part 2.	1 15 0	1 8 6
Part 3.	1 18 0	1 10 0
XXIV. Part 1.	1 5 0	1 1 0
Part 2.	1 8 0	1 3 0
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„ Part 3.	1 1 0	0 16 0
„ Part 4.	1 0 0	0 16 0
XXVIII. Part 1.	1 5 0	1 1 0
„ Part 2.	1 5 0	1 1 0
„ Part 3.	0 18 0	0 13 6
XXIX. Part 1.	1 12 0	1 6 0
„ Part 2.	0 16 0	0 12 0
XXX. Part 1.	1 12 0	1 6 0
„ Part 2.	0 16 0	0 12 0
„ Part 3.	0 5 0	0 4 0
„ Part 4.	0 7 6	0 5 8
XXXI.	4 4 0	3 3 0
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„ Part 2.	0 18 0	0 13 6
„ Part 3.	2 10 0	1 17 6
„ Part 4.	0 5 0	0 4 0
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„ Part 2.	2 2 0	1 11 0
„ Part 3.	0 12 0	0 9 6
XXXIV.	2 2 0	1 11 0
XXXV.* Part 1.	2 2 0	1 11 0
„ Part 2.	1 11 0	1 3 6
„ Part 3.	2 2 0	1 11 0
„ Part 4.	1 1 0	0 16 0
XXXVI. Part 1.	1 1 0	0 16 0
„ Part 2.	1 16 6	1 7 6
„ Part 3.	1 0 0	0 16 0
XXXVII. Part 1.	1 14 6	1 5 6
„ Part 2.	1 1 0	0 16 0
„ Part 3.	0 16 0	0 12 0
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TRANSACTIONS

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VOL. XXXVIII. PART IV.—FOR THE SESSION 1895–96.

CONTENTS.

PAGE

XXII. *Observations on the Phonograph.* By JOHN G. M'KENDRICK, M.D., Professor of Physiology in the University of Glasgow. (With Two Plates), ... 765
(*Issued separately, 25th November* 1896.)

XXIII. *On the Genus* Anaspides *and its Affinities with certain Fossil Crustacea.* By W. T. CALMAN, B.Sc., University College, Dundee. Communicated by Professor D'ARCY W. THOMPSON. (With Two Plates), ... 787
(*Issued separately, 26th October* 1896.)

XXIV. *On the* p*-discriminant of a Differential Equation of the First Order, and on Certain Points in the General Theory of Envelopes connected therewith.* By Prof. CHRYSTAL, 803
(*Issued separately, 16th November* 1896.)

THE COUNCIL OF THE SOCIETY, ... 829
ALPHABETICAL LIST OF THE ORDINARY FELLOWS, ... 831
LIST OF HONORARY FELLOWS AT MARCH 1897, ... 847
LIST OF ORDINARY FELLOWS ELECTED DURING SESSION 1894–95, ... 849
FELLOWS DECEASED OR RESIGNED, 1894–95, ... 850
LIST OF ORDINARY FELLOWS ELECTED DURING SESSION 1895–96, ... 851
FELLOWS DECEASED OR RESIGNED, 1895–96, ... 852
LAWS OF THE SOCIETY, ... 853
THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES, . 860
AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES, FROM 1827 TO 1896, ... 863
PROCEEDINGS OF THE STATUTORY GENERAL MEETINGS, ... 869
LIST OF PUBLIC INSTITUTIONS AND INDIVIDUALS ENTITLED TO RECEIVE COPIES OF THE TRANSACTIONS AND PROCEEDINGS OF THE ROYAL SOCIETY, ... 875
INDEX, ... 882

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XI.	0 14 6	0 12 0
XII.	0 14 6	0 12 0
XIII.	0 18 0	0 15 0
XIV.	1 5 0	1 1 0
XV.	1 11 0	1 6 0
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Part 4.	0 10 0	0 7 6
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Part 2.	0 10 0	0 7 6
Part 3.	0 7 0	0 5 3
Part 4.	0 18 0	0 13 6
XXII. Part 1.	1 5 0	1 1 0
Part 2.	0 10 0	0 7 6
Part 3.	1 5 0	1 1 0
XXIII. Part 1.	0 15 0	0 11 6
Part 2.	1 15 0	1 8 6
Part 3.	1 18 0	1 10 0
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„ Part 2.	0 6 0	0 4 6
„ Part 3.	1 1 0	0 16 0
„ Part 4.	1 0 0	0 16 0
XXVIII. Part 1.	1 5 0	1 1 0
„ Part 2.	1 5 0	1 1 0
„ Part 3.	0 18 0	0 13 6
XXIX. Part 1.	1 12 0	1 6 0
„ Part 2.	0 16 0	0 12 0
XXX. Part 1.	1 12 0	1 6 0
„ Part 2.	0 16 0	0 12 0
„ Part 3.	0 5 0	0 4 0
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XXXI.	4 4 0	3 3 0
XXXII. Part 1.	1 0 0	0 16 0
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„ Part 3.	2 10 0	1 17 6
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XXXIII. Part 1.	1 1 0	0 16 0
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XXXIV.	2 2 0	1 11 0
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„ Part 4.	1 1 0	0 16 0
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„ Part 3.	1 0 0	0 16 0
XXXVII. Part 1.	1 14 6	1 5 6
„ Part 2.	1 1 0	0 16 0
„ Part 3.	0 16 0	0 12 0
„ Part 4.	0 7 6	0 5 8
XXXVIII. Part 1.	2 0 0	1 10 0
„ Part 2.	1 5 0	0 19 0
„ Part 3.	1 10 0	1 3 0
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